MODERN
BIOLOGY

VOL. II

V.B. RASTOGI

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VOL. II
(For Class XII)

By

Dr. (Mrs.) V. B. RASTOGI
M. Sc., Ph. D., F.A.Z.
Department of Zoology,
Gargi College,
University of Delhi,
Delhi.

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PREFACE

Modern Biology provides a complete and detailed coverage of all the topics in Biology Syllabus framed by C.B.S.E. for Class XII. It gives to the students a clear understanding of the morphology and physiology of both plants and animals. It provides latest and updated information on such topics as inheritance, molecular genetics and introduces latest topics in the field of biological science like biotechnology, tissue culture, gene manipulation etc.

The subject matter is separated into five units as required in the syllabus framed by C.B.S.E. and NCERT. The Unit I covers the structure and functions in plants, Unit II deals with animals life. Unit III narrates the physical and chemical basis of continuity of life, Unit IV tells how life has evolved during the course of billions of years ending with the origin and evolution of human race. Unit V deals with the practical applications of biology highlighting the recent fields of research for the betterment of human race and providing them better eugenic and euphemic conditions, summarising the future of biology.

Writing a text-book which is readable yet sufficiently rigorous academically has not been easy. The author has tried her best to organize the subject matter in a way that makes the material easy to grasp and retain its continuity, so that the interest of the student is maintained and curiosity aroused.

The subject matter presents clearly one step at a time and the sequence of presentation indicates important interrelationships between various chapters. The contents are broken into small paras.

The author has been extra cautious to use small sentences; simple, clear and concise language. The technical terms used in the text are presented in bold and are defined so as to assist students in preparation for various entrance examinations.

An important feature of the book is generous use of accurate; detailed and fully labelled diagrams. This has been done to ensure quick comprehension of the subject matter and to arouse interest.

Since, to illustrate the text profusely, a number of Indian and foreign books have been used as a resource, no authenticity is claimed. As author is the final judge of all that is being presented in this book, she alone is responsible for errors and misinterpretation of facts.

The author is pleased to record her thanks to her collegues at various institutions all over the country, who have immensely helped her by their invaluable suggestions in preparing this book.

Suggestions for improvement of the book are not only welcome but will be greatly appreciated.

— Veer Bala Rastogi

Syllabus prescribed by CBSE, New Delhi for Biology Theory paper for Class XII

Unit	Marks
1. Multicellularity : Structure and Function — Plant Life	15
2. Multicellularity : Structure and Function — Animal Life	20
3. Continuity of Life	10
4. Origin and Evolution of Life	10
5. Applications of Biology	15

Unit 1 : Multicellularity : Structure and Function—Plant Life
15 Marks

Introduction : Multicellular way of life in plants and animals. The basic philosophy of form and function in plants and animals. Tissue system in flowering plants : meristematic and permanent. Mineral nutrition — essential elements, major functions of different elements, passive and active uptake of minerals. Modes of nutrition, transport of solutes and water in plants. Photosynthesis : photo chemical and biosynthetic phases, diversity in photosynthetic pathways. photosynthetic electron transport and photophosphorylation, photorespiration. Transpiration and exchange of gases, stomatal mechanism, Osmoregulation in plants : water relations in plant cells, thermodynamic concepts, water potential. Reproduction and development in plants : major forms of plant reproduction — asexual and sexual, brief account of mode of sexual reproduction in multicellular lower plants with emphasis on antheridia and archegonia. Structure and functions of flower : development of male and female gametophytes in angiosperms ; pollination, fertilization and development of endosperm, embryo, seed and fruit. Differentiation and organ formation. Plant hormones and growth regulation : action of plant hormones in relation to seed dormancy and germination, apical dominance, senesesoence and abscission. Applications of synthetic growth regulators. A brief account of growth and movement in plants. Photomorphogenesis in plants including a brief account of phytocι rome.

Unit 2. Multicellularity : Structure and Function—Animal Life
20 Marks

Animal tissues : epithelial, connective, muscular, nerve. Animal nutrition : organs of digestion and digestive processes, nutritional requirements for carbohydrates, proteins, fats, minerals and vitamins : nutritional imbalances and deficiency diseases. Gas exchange and transport : Pulmonary gas exchange and organs involved, transport of gases in blood, gas exchange in aqueous media. Circulation : closed and open vascular systems, structure and pumping action of heart, arterial blood pressure, lymph. Excretion and osmoregulation : aminotelism, ureotelism, uricotelism, excretion of water and urea with special reference to man. Role of kidney in regulation of plasma, osmolarity on the basis of nephron structure, skin and lungs in excretion. Hormonal coordination : hormones of mammals, role of hormones as messengers, and regulators. Nervous coordination : central, autonomic and peripheral nervous systems, receptors, effectors, reflex action, basic physiology of special senses, integrative control by neuroendocrinal systems. Locomotion : joints, muscle movements, types of skeletal muscles according to types of movement, basic aspects of human skeleton. Reproduction : human reproduction, female reproductive cycles. Embryonic development in mammals (upto three germ layers), Growth, repair and ageing.

Unit 3. Continuity of Life
10 Marks

Heredity and variation : Introduction. Mendel's experiments with peas and idea of factors. Mendel's laws of inheritance. Genes : packaging of hereditary material in prokaryotes — bacterial

chromosome; plasmid and eukaryote chromosomes. Cell division : Cell cycle, mitosis and meiosis. Extranuclear genes, viral genes. Linkage and genetic maps. Sex determination and sex linkage. Genetic material and its replication, gene manipulation. Gene expression : genetic code, transcription, translation, gene regulation. Molecular basis of differentiation.

Unit 4. Origin and Evolution of Life   10 Marks

Origin of life : Living and non-living; chemical evolution; organic evolution; Oparin Mendel's ideas, Miller—Urey experiments. Interrelationship among living organisms and evidences : Common features of life processes—energy transformation ; genetic code, protein synthetic machinery. Fossil record including geological time scale, Morphological evidence—homology, vestigeal organs, embryological similarities.

Darwin's two major contributions : Common origin of living organisms and recombination as sources of variability, selection acts upon variation, adaptation (Lederberg's replica plating experiment for indirect selection of bacterial mutants), reproductive isolation, speciation. Role of selection change and drift in determining gametic composition of a population. Selected examples : industrial melanism; drug resistance, mimicry, malaria in relation to G-6-PD deficiency and sickle cell disease. Human evolution : Paleontological evidence, man's place among mammals. Brief idea of *Dryopithecus, Australopithecus, Homo erectus, H. neanderthalensis,* Cromagnon man and *Homo sapiens.* Human chromosomes, similarity in different racial groups. Comparison with chromosomes of non-human primates to indicate common origin; Cultural *vs* biological evolution.

Unit 5 : Applications of Biology   15 Marks

Introduction. Role of biology in the amelioration of human problems. Domestication of plant—a historical account, improvement of crop plants : Principles of plant breeding and plant introduction. Use of fertilizers, economic and ecological aspects. Use of pesticides : advantages and hazards. Biological methods of pest control. Crops today. Current concerns, gene pools and genetic conservation. Under-utilized crops with potential uses for oilseeds, medicines, beverages, spices, fodder. New crops — *Leucaena* (Subabul), Jojoba, Guayule, winged bean, etc. Biofertilisers—green manure, crop residues and nitrogen fixation (symbiotic, non-symbiotic). Applications of tissue culture and genetic engineering in crops. Domestication and introduction of animals. Livestock, poultry, fisheries (fresh water, marine, aquaculture). Improvement of animals : principles of animal breeding. Major animal diseases and their control. Insects and their products (silk, honey, wax and lac.) Bioenergy—biomass, wool (combustion, gasification ethanol). Cow dung cakes, gobar gas, plants as sources of hydrocarbons for producing petroleum, ethanol from starch and lignocellulose. Biotechnology, a brief historical account–manufacture of cheese, yoghurt, alcohol, yeast, vitamins, organic acids, anti-biotics, steroids, dextrins. Scaling up laboratory findings to industrial production. Role of genetic engineering and tissue culture : production of insulin, human growth hormones, interferon. Communicable diseases including STD and diseases spread through blood transfusion (hepatitis, AIDS, etc.). Immune response, vaccines and antisera. Allergies and inflammations. Degenerative disease—symptoms and control. Inherited diseases and dysfunctions, sexlinked diseases, genetic incompatibilities, and genetic counselling. Cancer—major types, causes, diagnosis and treatment. Tissue and organ transplantation. Community health services and measures, blood banks. Mental health, smoking, alcoholism and drug addiction —physiological symptoms and control measures. Industrial wastes toxicology, pollution-related diseases. Biomedical engineering—spare parts for man, instruments for diagnosis of diseases and care. Human popullation growth, problems and control—inequality between sexes—Control measures ; test-tube babies, amniocentesis. Future of Biology.

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UNIT - IV
ORIGIN AND EVOLUTION OF LIFE

UNIT - V
PRACTICAL APPLICATIONS OF BIOLOGY

CHAPTER 1

Multicellular Way of Life

UNICELLULARITY AND MULTICELLULARITY

The bodies of all but the simplest organisms are made of cells. *Unicellularity* is restricted to sub-kingdom *Protista* and *Monera*. In them, the body is composed of single cell that performs all the life processes. The unicellular organisms make up more than half of the world's biomass, but for sheer number these cannot be rivaled to multicellular organisms.

Majority of living beings are *multicellular*, being formed of thousands, millions or billions of cells. In truly multicellular organisms, cells do not exist in isolation as in colonial aggregation of unicellular organisms, but are massed together so as to interact. These become specialized for carrying out one specific function most efficiently. Their association and interaction leads to the formation of tissues, organs and organ systems. These exhibit much diversity in form and function.

Necessity of Multicellularity

As a cell increases in size, its volume increases much more than its surface. Its surface becomes unable to provide sufficient food and oxygen for all the regions of cell, because diffusion over long distances is not effective. The waste produced within the cell have to move longer distance for being expelled out of the cell. The coordinating efficiency of its nucleus is also restricted to a limited volume. Therefore, a cell grows upto a limit of efficiency and then divides. In unicellular organisms the two daughter cells grow out into two individuals, while in multicellular organisms, the new cells stay together leading to growth of the body.

Cell Specialization and Division of Labour

Specialization and *division of labour* among body cells are two major features of multicellular organisms. As in an advanced human society different people are specialized for different jobs and

obtain a high skill in their own field. Similarly in multicellular organisms, individual cells are specialized to perform different functions. A few cells become better equipped to perform a specific vital function needed by entire organism, and can rely on other cells in the organism's body to do some other function. For example, muscle cells are specialized for contraction, nerve cells for conduction of sensory and motor impulses, conducting tissue in plants for transport of materials. This provides for increased efficiency.

Thus all the cells carrying out same function assume similar appearance and structure. These exihibit *structural modification related to physiological division of labour.*

Tissues, Organs and Organ Systems

A group of closely associated cells that have common origin, similar structure and carry out specific function form a *tissue*. Tissue level of organization is seen for the first time in Coelenterata (= *Hydra*) in animal kingdom and in Bryophyta (= moss) in plant kingdom.

In most plants and animals, specialization does not stop at tissue level. Different tissues associate to perform a special function jointly and make up an *organ*. Because of basic difference in mode of life, the tissues and organs in plants and animals are constructed on totally different plans.

In both plants and animals, organs do not function in isolation. For example, intestine helps in digestion and absorption of food but it has to be assisted with organs like mouth, pharynx, oesophagus and stomach etc. These organs along with salivary glands process the food so that it can be digested in intestine. Therefore, a group of organs of like function or shared responsbility constitute *organ system*. The tissues, organs and organ systems are specialized to increase the

efficiency of the organism as a whole.

Advantages of Multicellularity

Multicellularity confers following significant advantages to the organisms—

1. **Increased efficiency** —Division of labour and specialization of cells increases the efficiency of the organisms as a whole.

2. **Protection** —In multicellular organisms the outer layer of cells specialize to protect cells of the interior from environmental shocks such as mechanical abrasion, change of pH and toxic substances.

3. **Invasion to various environments** —Evolution of protective, conducting system and other systems for support and movement enabled multicellular organisms to live in diverse environments. This opened new terrestrial habitats to the initially aquatic living world.

4. **Variety of shapes** —Development of supporting tissues enabled the organisms to acquire a nearly infinite variety of shapes and great diversity of body plans.

5. **Increased size** —A unicellular organism is unable to cope with the problems created with an increase in size. However, size has great advantages for multicellular organisms. For example, multicellular green plants can have extensive *root-system* for anchoring and obtaining water and minerals and also an elaborate *shoot-system* with a canopy of light gathering leaves that can synthesize food for the plant. A large plant will cut the availability of light to smaller plants. Similarly, a large animal may prove more formidable fighter and predator than a small one.

Problems Associated with Multicellularity

The multicellular way of life poses a number of problems which have led to the development of various organ-systems or mechanisms. These are :

1. **Digestive system** —for providing nourishment to every cell of the body.

2. **Transport system** or **circulatory system** to distribute water, food etc. within the body.

3. **Respiratory system or gas exchange mechanism** for obtaining oxygen for oxidation of food stuff and release of energy.

4. **Excretory system** for removing waste products of metabolism from every body cell.

5. **Skeleton** —Either exo- or endoskeleton for providing structural support, to acquire specific form and to assist in locomotion.

6. **Nervous system** for the coordination of activities of various body organs.

7. **Locomotory organs** in mobile forms.

8. **Reproductive system** to ensure continuity of race by producing new individuals.

Based on the ways of solving the above mentioned problems the multicellular world has been divided into three kingdoms:

1. Kingdom—*Fungi*
2. Kingdom—*Plantae* or Plant kingdom.
3. Kingdom—*Animalia* or Animal kingdom.

Origin of Multicellularity

Multicellularity is a common form of organization. Most probably it has evolved independently several times in the living world. There are only two possible paths for the origin of multicellularity :

1. **By aggregation of cells** —Sponges in animals and Fungi are regarded to have evolved by the aggregation of once independent unicellular organisms to form a colony. Within the colony, different clusters of cells became specialized for particular functions and lost their capacity to survive independently.

2. **By multinucleation** —Multicellularity in plants and animals is supposed to have evolved by this method. The uninucleate protist cells became multinucleate, then partitioned themselves into united uninucleate cells and finally differentiated.

Evolutionary biologist *Earl Hanson* has supported this view by tracing striking similarities between flatworms and some present day multi-nucleate protists.

Questions

1. Discuss advantages of multicellularity to living organisms.
2. Justify "that multicellular organisms have an advantage over unicellular organisms".
3. Write a note on the origin of multicellularity in animal world.
4. Explain why it is not possible for a unicellular organism to grow beyond a specific size.

CHAPTER 2

Tissue System in Flowering Plants
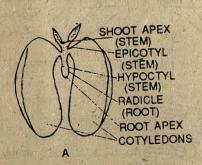
TISSUES

Tissue is a group of cells which resemble one another in form and structure and carry on the same function and have a common origin. Tissues are primarily of two fundamental types—the *meristematic* and *permanent*.

A. MERISTEMATIC TISSUES

Plant begins life as a single fertilized egg cell. By numerous divisions it gives rise to a young embryo which in turn grows into a seedling, and then into a young plant.

length, and production of leaves, branches and flowers. *These localised young groups of undifferentiated cells, which primarily lead to the formation of new cells, are called the meristems* (Greek, *meristos*, meaning divisible).

In bean seed (dicot), embryo lies within the two cotyledons, whereas in monocots, it lies on one side of the cotyledons. The axis of the embryo consists of *plumule* or *shoot apex* and *radicle* or *root apex*. The cells of the shoot apex or plumule give rise to the *shoot system* and radicle or root apex gives rise to *root system*.
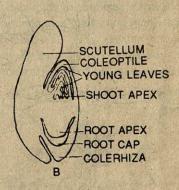
Fig. 2.1A (A) Dicotyledonous embryo; (B) L.S. of a monocotyledonous embryo

In the early stages, all the cells of the embryo divide. Later, the cell division is restricted to certain parts of the plant body, and the other parts take up different functions.

The embryonic tissues persist throughout the life of the plant and are responsible for the growth in

Characteristics of Meristematic Tissue

Meristematic tissue is a group of young cells that are in a continuous state of division or retain their power of division. The main characteristics of the cells of meristematic tissue are:

1. They may be rounded, oval, polygonal or rectangular in shape.
2. They have their walls made up of cellulose.
3. They lack intercellular spaces between them.
4. They have dense granular cytoplasm, large and conspicuous nuclei.
5. They do not have vacuoles.
6. They do not store reserve food material and are in an active state of metabolism.
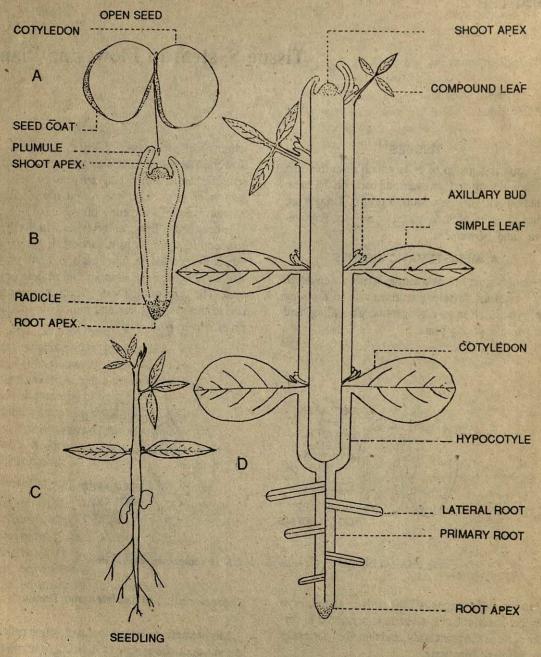
Fig. 2.2. (A) Organisation of seed cotyledons opened to show the embryo
(B) shoot apex and root apex in the embryo (C) a seedling and (D) of a seedling

Types of Meristems

Meristems may be classified on the basis of their mode of origin, position or function.

(A) According to their Origin and Development

On the basis of origin, meristematic tissues are of three kinds:

1. **Promeristem or Primordial Meristem**—It is the region of new growth in the plant body, where the foundation of new organs or parts is laid. It occupies a small area at the tips of stem and root. The promeristem gives rise to all other meristems including the primary meristem.

2. **Primary Meristem**—It is derived from the promeristem and retains its meristematic activity. It is located in the apices of roots, stems and the leaf primordia. Primary meristem gives rise to the primary permanent tissues. **Vascular cambium,** which gives rise to secondary permanent tissues is also primary meristem.

3. **Secondary Meristem**—It develops in the primary permanent tissues and gives rise to the secondary permanent tissues which add to the girth of the plant. The cambium of root, interfasicular cambium of stem and cork cambium in both root and stem are secondary meristem.

(B) According to their Loction in the Plant Body

According to their position in the plant body meristems are put into three categories—apical, intercalary and lateral.

1. **Apical Meristem**—It is found at the apices of the stems and roots, *i.e.* at the growing points.

Apical meristem consists of a group of cells which give rise to primary permanent tissues which together constitute the primary body of the plant.

2. **Intercalary Meristem**—These are the portions of apical meristems which are separated from the apex during the growth of axis and formation of permanent tissues. Intercalary meristem also has the same functions as apical meristem. It is usually found at the nodes in *grasses* and at the base of leaf as in *mint.*

Intercalary meristem is short lived. It soon becomes permanent and merges with the surrounding tissue.

3. **Lateral Meristem**—These meristems occur laterally in the axis, parallel to the sides of stems and roots. These are composed of cells which are rectangular in shape and divide tangentially. The
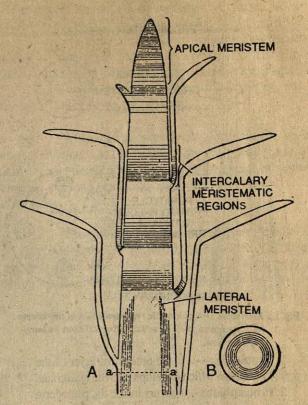
Fig. 2.3. **Meristems Diagram showing positions of meristems in the L.S. of a shoot.**

cambium of vascular bundles and *cork cambium* are the examples of lateral meristem and are found in dicotyledonous plants and gymnosperms. The lateral meristem is responsible for increase in thickness by the addition of *secondary tissues,* and this phenomenon is called the *secondary growth.*
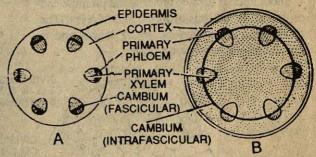
Fig. 2.4 **Lateral meristems (A) Fascicular X intrafascicular cambium ; (B) Cambium ring formed from fascicular and intrafascicular cambium.**

(C) According to the Function in the Plant Body

HABERLANDT in 1890 classified the primary meristem at the apex of the stem into *protoderm, procambium* and *ground meristem.*
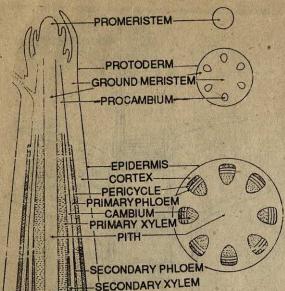
Fig. 2.5 Meristem. Diagrammatic representation of meristems in a stem and their gradual differentiation in longitudinal view.

1. **Protoderm**—It is the outermost layer of the apical meristem which develops into the *epidermis*.

2. **Procambium**—It occurs inside the protoderm and gives rise to the *vascular tissues*.

3. **Ground Meristem**—It constitutes the major part of the apical meristem and develops ground tissues like *cortex* and *pith*.

STRUCTURE AND ORGANISATION OF APICAL MERISTEMS

Vegetative Shoot Apex

Shoot apex is formed either at the plumule end of the embryonal axis or in the axil of a leaf. The shoot apex is covered by young leaves and is visible only after their removal.

The tip of the shoot apex is dome-shaped. The cells from its flanks at the base of the dome divide to form one or more of leaf primordia. This continues throughout the vegetative phase.

In angiosperms, the cells divide in several planes and ultimately organize them into two zones, the *tunica* and the *corpus*. The tunica constitutes one or more peripheral layers. In this case wall formation during cell division takes place anticlinally *i.e.* at right angles to the surface of the apex. This results in the surface growth. The inner mass of cells is called the *corpus*, where the cell divisions occur in all directions resulting in
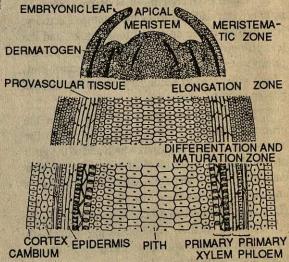
Fig. 2.6 Longitudinal section of the shoot apex.

increase in volume.

When there is more than one tunica layer, the outer layer contributes to the *epidermis* while the other layers take part in the formation of the *leaf*
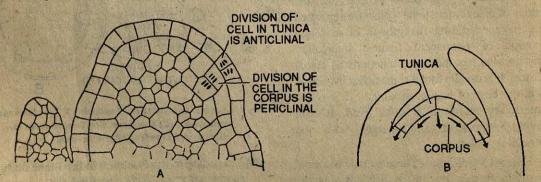
Fig. 2.7 L.S. OF shoot apex showing tunica and corpus

primordia and *cortical tissues*. The corpus takes part in the formaion of the *cortex* and *vascular tissues*.

Depending upon the rate of cell division, two regions can be recognised in the shoot apices—the summit and the flanks.

There are few cell divisions at the apex, whereas the rate of cell division is high at the flanks, from where the leaf primordia arise. Just below the summit, the cells towards the surface and the centre, *i.e.* the future cortex and pith, mature early. The cells between the surface and centre remain meristematic and produce the *procambium*. The procambium gives rise to the *vascular bundles*.

Reproductive Apex

During reproductive phase, the vegetative apices are converted into reproductive apices. Before conversion into the reproductive phase, the apex stops producing leaf primordia. The summit of the apex which remained inactive during the vegetative phase, starts dividing. As a result of cell divisions, the apical meristem undergoes change in shape and increases in size. The apex may develop into a flower or an inflorescence.

When the apex is to develop into a single flower, the cells at the flanks of the apex produce sepals and petals while the cells in the centre of summit produce stamens and carpels.

Root Apex

The root apex is differentiated from the opposite end of the embryonic axis, *i.e.* radicle. Unlike the shoot apex, which is apical, the root apex is subterminal because it is covered by the root cap.
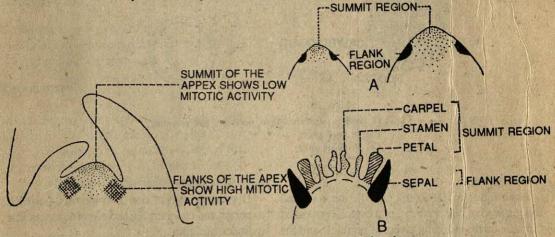
Fig. 2.9 Transformation of shoot apex from the vegetative to the reproductive phase.
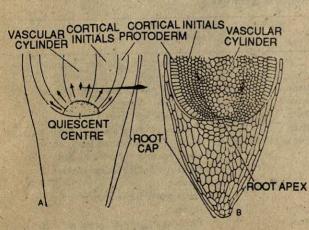
Fig. 2.10 L.S. of root tip showing quiescent centre in the root apex.

The root apex also differs from the stem apex in not having lateral appendages.

The root apex shows three meristematic regions for the future *epidermis* (protoderm), *cortex* (*cortical* initials) and *vascular cylinder*. A group of initials at the apex produces cells towards the axis which form the epidermis, cortex and vascular cylinder and produce the root cap in the opposite direction.

Quiescent Centre

According to CLOWES, a British plant anatomist, a few cells located in the central part of the region above the root apex show low mitotic activity, called the *Quiescent Centre*. The cells in this region have a lower concentration of DNA, RNA and proteins as compared to other cells

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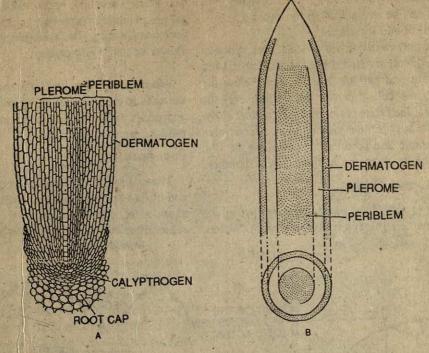
Fig. 2.11 Position of dermatogen, periblem and plerome.
(A) in root apex;
(B) in shoot apex

in the root apex.

According to HANSTEIN (1870), the root and shoot apices of plants consist of a central core called plerome, surrounded by layers of periblem and the outermost single layer of *dermatogen*.

Dermatogen gives rise to epidermis, periblem to cortex and endodermis, and plerome to vascular cylinder and pith.

Table 2.1: Classification of Meristems

Criterion	Type of Meristem	Examples
1. Growth initation	Promeristem	Apical meristems and their immediate derivative
2. Development	(a) Primary meristem	Stem and root epidermis and primordia of leaves.
	(b) Secondary meristem cork	
3. Position	(a) Apical meristem	Short apex, root apex.
	(b) Lateral meristem	Vascular cambium and cork Cambium,
	(c) Shoot apex, root and intercalary meristem	Bases of internodes and leaves of grass, peduncles of certain plants.
4. Function	(a) Protoderm	Gives rise to the primary vascular tissues.
	(b) Procambinn	Gives rise to the primary vascular tissues.
	(c) Growth meristem	Precursor of ground (cortex and pith) tissue

Shoot Apex	Root Apex
1. It is apical in nature	1. It is subterminal in nature.
2. It is protected by young leaves.	2. It is protected by root cap.
3. Bears lateral appendages in the form of leaf primordia.	3. Does not bear lateral appendages.

B. PERMANENT TISSUES

A permanent tissue is a group of cells in which the growth has either stopped completely or for the time being. These cells may be dead or alive, thin-walled or thick-walled. Permanent tissues have been classified as (i) simple, (ii) complex, and (iii) special or secretory.

1. Simple Tissues

Simple tissue is a group of cells which are all alike in origin, form and function. The following are the main types of simple tissues—

(a) Parenchyma

It is an aggregate or collection of living and isodiametric cells which are oval, spherical or polygonal in shape. The parenchyma forms the major part of the nonwoody and softer tissues of the higher plants and the entire thallus as in *bryophytes*.
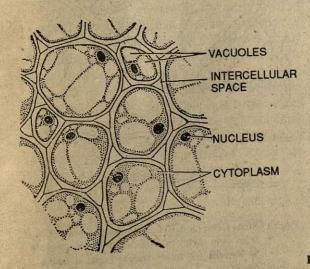
Fig. 2.12 Parenchyma.

Each cell has a thin cell-wall of cellulose and a large vacuole. The cells have intercellular spaces filled with air.
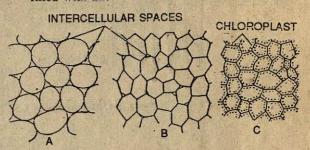
Fig. 2.13 (A-B) Parenchyma; (C) Chlorenchyma.

Functions

1. It serves mainly for the storage of food material.
2. When the parenchymatous cells contain chloroplasts, the tissue is known as *chlorenchyma* and functions as the *assimilatory tissue* and helps in the mnufacture of food.
3. In aquatic and marshy plants, there are very large and conspicuous air cavaties, and the tissue is called *arenchyma*. It is also found in petiole of banana and *Canna*. It helps in
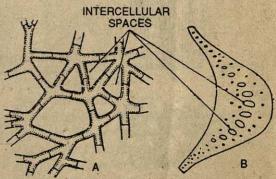
Fig. 2.14 Aerenchyma (A) In petiole of Canna; (B) In midrib midrib of Canna leaf.

THICKENING ON CORNERS
DUE TO DEPOSITION OF
CELLULOSE AND PECTIN

UNEVEN
THICKENED
WALLS

LUMEN
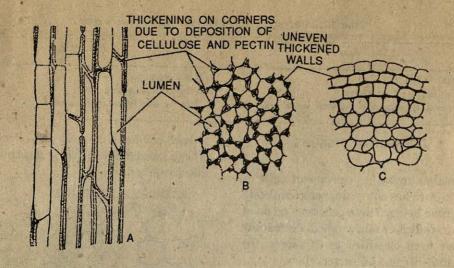
Fig. 2.15 Collenchyma (A) L.S.; (B & C). T.S. of the same

RAMIFORM PIT

SIMPLE PIT

REDUCED LUMEN
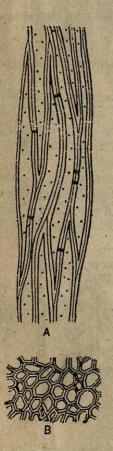
Fig. 2.16 Sclerenchyma fibres (A) L.S.; (B) T.S.
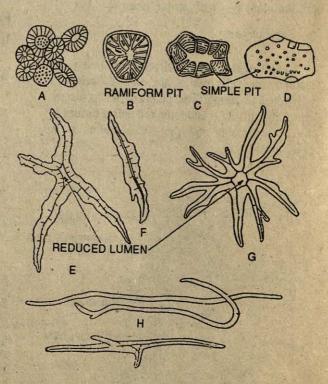
Fig. 2.17 Stone Cells: (A & B) from the pulp of pear; (C & D) from stem cortex of Hoya; (E & F) from petiole of Camelis; (G) from mesophyll cells of leaf. & (H) from stem cortex of Trochodendron.

aeration of the tissues and in aquatic plants it also provides buoyancy.

4. Owing to the turgid condition of its cells, parenchyma makes the stems turgid. This helps in maintaining the form of herbaceous plants.

5. It also helps in the conduction of food, water and raw materials.

(b) Collenchyma

It is commonly found as 3-4 layered hypodermis beneath the epidermis in herbaceous plants. It is absent in roots and monocotyledons except in some special cases.

Cells of collechyma are longer than parenchyma cells. They are living. The cell walls are thickened at the corners and are made up of *cellulose* and *pectin*.

Functions

1. Provides mechanical support to the organs and in stems it resists bending and pulling action of wind.

2. When chloroplasts are present, it takes part in the photosynthesis.

(c) Sclerenchyma

Sclerenchyma forms the main strengthening tissue of the plants. It consists of thick-walled and heavily lignified dead cells. They are of various shapes and size. They are of two types—*fibres* and *stone cells*.

(i) **Fibres**—These are greatly elongated and tapering at both the ends. In some cases the cell wall is so much thickened that the lumen is greatly reduced. The fibres which occur in the pericycle and phloem and have simple pits in their walls, are known as *bast fibers*, and those which are associated with wood or xylem have bordered pits and are known as *wood fibres*. The length of fibres is 1-3 mm but in jute and Buehmeria their length may be from 20-550 mm. In addition to jute, the fibres are of common occurrence in plants like hemp, agave and flax.

Function — Sclerenchyma provides mechanical strength to the organs in which present.

(ii) **Stone cells or sclereids**—The cell walls of stone cells are extremely thickened and strongly lignified. Their cell lumen is almost obliterated. These may be spherical, oval, cylindrical or stellate. These are found in the seed coat of leguminous plant, endocarp of walnut and coconut.
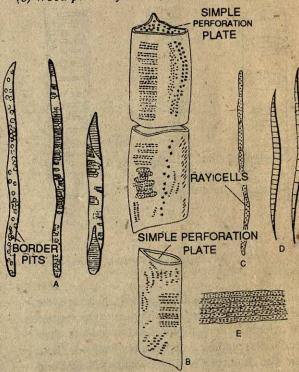
2. Complex Tissues

Complex tissues are comprised of different kinds of cells, all adapted to perform a common function and work together as a unit, *xylem* and *phloem* are two main complex tissues.

1. Xylem

It is a complex tissue meant for upward conduction of water and minerals from the roots to the aerial parts of the plant. Xylem consists of the following four types of cells:

(a) *Tracheids* (b) *Xylem vessels*
(c) *Wood parenchyma* (d) *Wood fibres*

Fig. 2.18 Xylem : (A) Tracheids, (B) Vessels or tracheae; (C & E) Xylem parenchyma, (D) Wood fibres (Wood parenchyma).

(a) **Tracheids**—These arise from the prosenchymatous cells which are elongated and tapering at both the ends. These are tube-like dead cells with thick and lignified walls. The cells have large lumens or cavities and the walls are provided with pits. The tracheids are thickened variedly owing to the deposition of *lignin*. When the thickening is *annular, spiral* or *scalariform* it is provided with *bordered pits*. In case of *pitted*

tracheids simple pits are present. The tracheids are commonly found in the vascular tissues of the ferns and gymnosperms. In angiosperms they occur in the association of vessels.

Function—The tracheids are mainly concerned with the conduction of water and minerals from the root to the leaf. As they are hard and lignified they also provide strength and mechanical support to the plant.

(b) **Vessels**—These are also known as *tracheae* and resemble the tracheids vey much in structure

assist in the conduction of water upwards through the tracheids and vessels.

(d) **Wood fibres**—These are dead *sclerenchymatous fibres*. They are known as *wood fibres* because of their association with xylem. They provide mechanical strength to the plant body.

2. Phloem

Phloem is another type of complex tissue. It aids in the conduction of such foods as amino acids and carbohydrates from the leaves down the stem to
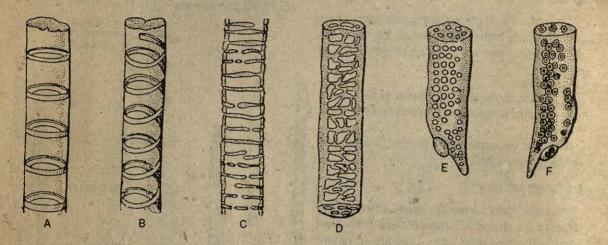
Fig 2.19 Various kinds of vessels (A) Annular; (B) Spiral; (C) Scalariform; (D) raticulate; (E & F) pitted.

and function. But unlike tracheids, these are like the long tubes arranged in vertical rows formed of cylindrical cells arranged end to end with their end walls completely or partially dissolved. These are also dead cells with their walls thickened and lignified in vairous ways. On the mode of thickening, these vessels are known as *annular, spiral, scalariform* or *pitted*. Vessels are absent in pteridophytes and gymnosperms.

Function—Vessels along with tracheids form the main tissues of xylem of vascular bundles of the angiosperms.

(c) **Wood parenchyma**—These are the living *parenchymatous cells*. As found associated with xylem, they are known as the *wood parenchyma*. They serve for the storage of reserve food and also

the trunk, roots and other parts of the plant. It is composed of the following types of cells:

(a) *Sieve tubes*
(b) *Companion cells*
(c) *Phloem parenchyma*
(d) *Phloem fibres or Bast-fibre*

(a) **Sieve tubes**—The sieve tubes are composed of living, slender, and elongated tubular cells placed end to end. They have large cavities. The cell walls are thin and made up of *cellulose*. The transverse walls are obliquely placed and are perforated by a number of pores called the *sieve pits*. Transverse walls with the sieve pits are known as *sieve plates*. Sieve tubes have no nuclei but the
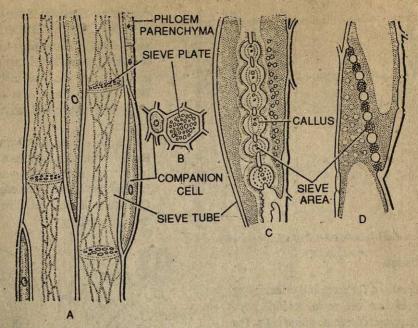
Fig. 2.20 Phloem (A) L.S. phloem tissue; (B) T.S. phloem; (C) Sieve tubes; (D) L.S. Sieve plate.

living layers of protoplasmic strands have the direct continuity through the sieve plates from one sieve tube to the other. They aid in the conduction of synthesised food such as amino acids and carbohydrates from the leaves to other regions of the plant body.

(b) **Companion cells**—They have derived this name because of their association with sieve tubes. These are living elongated cells with thin walls lying parallel to the sieve tubes. Each companion cell has a prominent nucleus and contains dense cytoplasm which is in direct continuity with that of sieve tube by means of cytoplasmic strands. It is assumed that the nucleus of companion cell regulates the activities of the sieve tubes.

Companion cells are found in *angiosperms*. They are completely lacking in *pteridophytes* and *gymnosperms*.

(c) **Phloem parenchyma**—These are living cylindrical *parenchymatous* cells. They are usually absent in *monocotyledons*.

(d) **Phloem fibres or bast fibres**—These are the *sclerenchymatous cells* commonly found in secondary phloem but absent in primary phloem.

3. Complex or Special Tissues

These are special structures or glands associated with the secretion or excretion of certain products like gums, resins, latex, etc. They are of two types :
(A) *Laticiferous tissue*
(B) *Glandular tissue*

(A) Laticiferous

It consists of thin-walled, much-branched and elongated ducts. These ducts secrete the milky juice called the *latex*. The *laticiferous ducts* contain numerous nuclei lying embedded in the thin parietal layer of protoplasm. These ducts are supposed to serve as reservoirs of waste-products or food storage organs. It is of two types :

(a) **Laticiferous cells**—These are single but very much elongated and branched cells. They are coenocytic and their walls are made of cellulose. They are commonly found in *Oleander*, *Euphorbia*, India-rubber plant, etc.

(b) **Latex vessels**—These are rows of cells formed by the fusion of large number of cells. They are also coenocytic and are commonly found in garden poppy, opium poppy, *Sandelion*, etc.
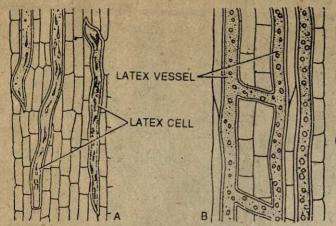
Fig. 2.21 (A) Laticiferous vessels; 2.21 (B) Laticiferous cells.

(B) Glandular tissue

The cells specialised for secreting or excreting certain substances like oil, resin, tannin, gum, mucilage and water, etc. constitute *gland cells*. The glandular tissue is formed of parenchymatous cells, having large amount of granular cytoplasm with a conspicuous nucleus. These cells may remain isolated to form the *unicellular glands* or might be grouped forming *multicellular glands*. Depending upon their location, these might be **internal** or **external**.

1. External glands—These are found on the epidermis of stem and leaves as glandular outgrowths, *e.g.* glandular hair, nectar secreting and enzyme secreting glands.
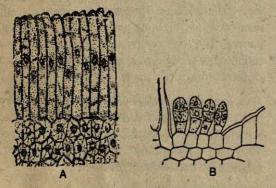
Fig. 2.22(A) Nectar secreting glands (A) Euphorbia; (B) Vicia.

(i) **Glandular hair**—These are present in the epidermis of leaves. These may be unicell-

ular and multicellular. Stinging hair on the under surface of *Urtica dioica* (Bichu buti) are unicellular, arising from lower epidermis of leaf. Contents of hair are poisonous and are secreted by the gland at the base of hair. When struck sharply, the hair injects an albuminous poison and causes irritation and blisters.

(ii) **Nectaries**—Found in flowers and leaves. In **Rutaceae** they are found as a disc below the ovary. In *Euphorbia pulcherrima*, the nectaries are found on the edge of involcure. Cell walls of these cells are thin and with dense cytoplasm.
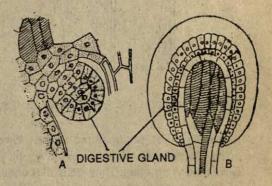
Fig. 2.22(B) Digestive glands (A) Nepenthes; (B) Drosera.

(iii) **Digestive glands or enzyme secreting cells**—Insectivorous plants digest proteins from the bodies of insects by secreting the digestive enzymes, *e.g. Drosera* (sundew).

2. Internal glands—These are of following types:
(i) **Oil glands**—These are found in the fruits and leaves of citrus fruits like lemon, orange and coriander.

(ii) **Resin glands**—These are found in certain plants of sunflower family and in the leaves and stems of *Pinus*. These glands form one or two peripheral layers that surround a schizogenously developed duct.

(iii) **Water secreting glands or hydathodes**—These are unicellular or multicellular water secreting glands. These may be unicellular or multicellular hairs. They are found on the leaves of aquatic plants or herbaceous palnts growing in moist places. These occur at the tip or in the margins of leaves. Each hyda-
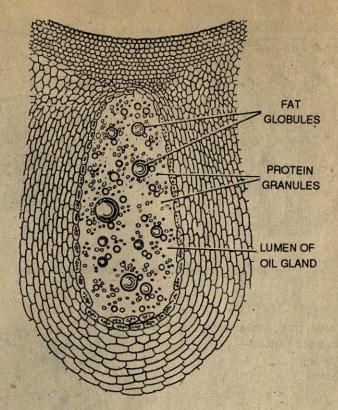
Fig. 2.23 Oil gland in the rind of Cirtus.
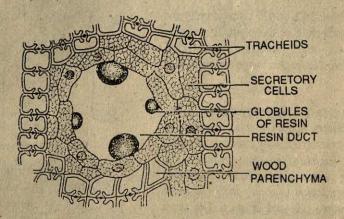
Fig. 2.24 Resin secreting glands in the resin duct of Pinus.

thode consists of a group of loosely arranged living cells with large intercellular spaces filled with water. These cells are called *epithelial cells*. The open out into a *stomatal* cavity which opens through water pore or stoma to the exterior. hydathodes help in the exudation of water in the liquid form.

Eudation takes place in plants like water hyacinth, *Pistia* and garden nastortium during moist and cool nights following warm summer days.

THE TISSUE SYSTEM

A tissue system consists of one or more kinds of tissues, which together act as a unit, adapted to
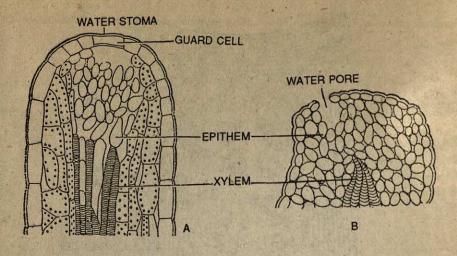
Fig. 2.25 L.S. of hydathode in Pistia; hydathode in tomato.

carry on a common function or a set of functions. There are three main tissue systems—

1. *Epidermal tissue system*
2. *Vascular tissue system*
3. *Vascular tissue*

1. Epidermal Tissue System

Epidermis consists of a single layer of cells and forms the outer covering of the plant. It performs several functions, *e.g.* protection, absorption, excretion, secretion, gaseous exchange and regulation of transpiration.

Epidermis consists of a single layer of cells. The cells are of different shapes and size and form a continuous layer interrupted by *stomata*. In plants like *Nerium, Ficus, Banyan* epidermis is multilayered. In water plants, ferns and shade plants, the epidermal cells may contain chloroplasts, tannins, oils and crystals. The outer walls of epidermal cells have a deposition of *cutin* are *suberin*. The cuticle protects the epidermal cells from mechanical injuries and retards transpiration.

In some monocot leaves, epidermal cells become larger, thin-walled and have vacuoles. Such cells are called *bulliform cells*. These cells bring about rolling of leaves during dry season and this reduces transpiration as in *Ammophila*.
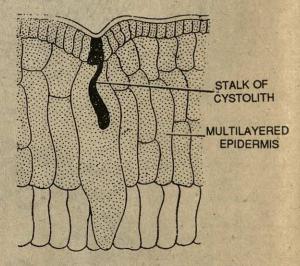
Fig. 2.26 Multilayered epidermis in Ficus.

In roots, the outermost layer is called *epiblema* or *piliferous layer*. Outer walls of some cells of this layer develop unicellular tubular extensions, the *root hairs*. These help in absorption of water and minerals from the soil. Epiblema does not have cuticle.

Stomata —These are minute apertures in the epidermis. Each stoma or aperture is bounded by two kidney-shaped cells, the *guard cells*. Stomata are not found in roots.

In xerophytes, the stomata are found sunken in grooves. This greatly reduces the rate of
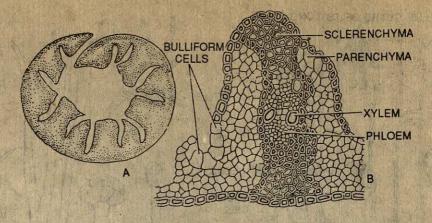
Fig. 2.27 (A) T.S. of rolled leaf of Ammophila; (B) Enlarged view of A.
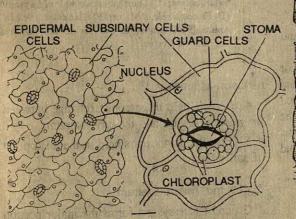
Fig. 2.28 (A) Stomata on the lower surface of a dicot leaf. (B) Detailed structure of one stomata.

Fig. 2.29 Nerium leaf showing thick cuticle, multilayered epidermis, sunken stomata and stomata hair.

transpiration. Each stoma opens below in a large cavity, called *substomatal cavity*. In some monocots like doob and maize, the guard cells are dumbell-shaped. In certain plants some specialized epidermal cells are present. These are called *subsidiary cells* or *accessory cells*.

Guard cells are living and contain chloroplasts. In the leaves of dicot plants, the stomata are scattered on the surface, whereas in monocots they are arranged in straight lines.

In bifacial (dorsiventral) leaves stomata are localized mainly at the lower epidermis. In isobilateral leaves of monocotyledons, they are found in equal number on both the surfaces of the leaves. In floating leaves, stomata are found on the upper epidermis and in submerged plants, stomata are absent.

Number of stomata may vary from 14 to 1038 per sq. m.m. In most plants this number is from 50-300. About 1-2% of the total leaf area is
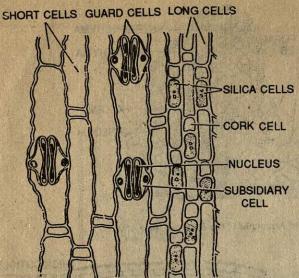
Fig. 2.30 Stomata on the surface of maize leaf.

Fig. 2.31 (A) Stellate hair of Allyssum, (B) Glandular hair of Pelargonium; (C) Short glandular hair of Layandula, (D) Floccose hair of Malva; (E) Glandular hair of Solanum; (F) Urticating hair of Verbascum; (G) Stinging hair of Cestus.

covered by stomata.

Stomata help in exchange of gases and regulation of transpiration.

Hairs or trichomes—These are unicellular or multicellular appendages originating from epidermal cells. These may be simple, branched or star-shaped. Cotton fibres of commerce are the unicellular epidermal hairs of the cotton seeds. These hairs have thickened cellulose wall, dead and filled with air.

Trichomes or hairs may be of the following types.

(a) Stellate hair.
(b) Glandular hair
(c) Short glandular hair.
(d) Floccose hair.
(e) Utricating hair
(f) Stinging hair

The trichomes serve for checking excess of water and for protection.

Functions of Epidermis

1. It protects the internal tissues against mechanical, injury, the parasitic fungi and bacteria and also against cold or heat.

2. Thick cuticle, wax, epidermal hairs and multiple epidermis reduce the loss of water from internal tissues.

3. Glandular hairs of the epidermis, as in stinging nettles, protect the plants from herbivorous animals.

4. Stomata help in gaseous exchange between the internal tissues and the environment.

5. Unicellular root hairs help in the absorption of soil water.

2. Ground Tissue System

Ground tissue system forms the major portion of the young root, stem and leaves. It is largely composed of parenchymatous cells. All the tissues in stem and root extending from below the epidermis to the centre excluding the vascular bundles constitute ground tissue system.

The ground tissue system constitutes the following parts —

1. Cortex
   (a) Hypodermis
   (b) General cortex
   (c) Endodermis

2. Pericycle
3. Medulla or pith.

In monocotyledons, the ground tissue is not differentiated into cortex, pericycle and pith.

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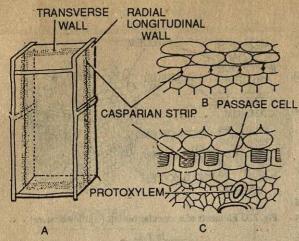
Fig. 2.32 Casparian strips and passage cells in the endodermis;
(A) Endodermal cells showing casparian strip. (B) and
(C) Endodermal cells in T.S.

1. Cortex

Cortex lies between the epidermis and the pericycle. It is differentiated into the following tissues —

(a) **Hypodermis**—In dicot stems it is found below the epidermis in the form of one or more continuous layers or patches of collenchymatous cells. In monocot stem it is sclerenchymatous. In stems with grooves and ridges, as in *Cucurbitacae*, hypodermis is present only below the ridges.

Function—In young stems, it provides mechanical support and is protective in function.

(b) **General cortex**—It may be few to many layered in thickness. The cells are thin-walled parenchymatous. These may be rounded, polygonal or cylindrical. Cells have intercellular spaces and store starch grain, oil, tannins and crystals of various types. In young plants, cortical cells possess chloroplasts and are called *chlorenchyma*.

Functions 1. Cortex carries the function of storage of reserve food material.

2. When chloroplasts are present, it carries the function of photosynthesis.

(c) **Endodermis** Forms the inner boundry of the cortex. It is composed of a single layer of vertically elongated cells with transverse end walls. In transverse section it appears as a layer of barrel-shaped cells without intercellular spaces. The cells are living and may contain starch grains. A special thickened band is present on radial and tangential walls of endodermal cells. This is called *casparian strip*. It is made up of lignin, suberin and cutin.

A distinct endodermis is present in all roots but it is not distinct in stem. In roots thick walled endodermal cells are interrupted by thin walled cells just opposite the protoxylem patches. These thin-walled cells are called *passage* cells. They help in passage of water from cortex to xylem.

Functions
1. Endodermis forms a watertight barrier between vascular and nonvascular regions.

2. It stores starch.

3. It serves as a protective layer and maintains root pressure.

2. Pericycle

It lies immediately below the endodermis. It may be single layered or multilayered. In roots it is one cell thick and consists of parenchymatous cells. In dicotyledonous stems the region between the vascular bundles and cortex is called the pericycle. It is multilayered and may be homogenous or heterogenous in nature. In *Cucurbita* stem, it is sclerenchymatous, but in sunflower it is heterogenous as the sclerenchyma occurs in the form of separate patches.

Functions
1. The lateral and adventitious roots arise from the pericycle.

2. In dicot roots, the pericycle cells becomes meristematic and forms part of the cambium ring.

3. Thick walled pericycle gives rise to lateral roots.

3. Medulla or pith

It occupies the central part in dicot stem and dicot and monocot roots. It is composed of parenchymatous cells with intercellular spaces. In dicot roots pith is more or less obliterated by the metaxylem elements.

In dicotyledon stems vascular bundles are separated from each other by radial rows of parenchymatous cells. These arise from the central pith and extend upto the pericycle. These radial rows of parenchymatous cells are called medullary rays.

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Functions

Medulla or pith has following functions —

1. When sclerenchymatous, it serves as a supporting column.
2. Helps in the conduction and storage of water and food materials.
3. Medullary rays serve mainly for the conduction of food and water radically.

3. Vascular Tissue System

Vascular tissue system comprises of a number of vascular bundles arising from the plerome region of apical meristem. The vascular bundles are used for the conduction of water, mineral salts and manufactured food. Xylem elements of the bundles are also associated with the mechanical support and strength to the body. The vascular bundles may be regularly arranged either in a ring as in dicot stems and all roots or may be scattered in the ground tissue as in monocot stems.

Elements of Vascular Bundle

Each vascular bundle consists of xylem and phloem with cambium in dicot stems and without cambium in monocot stems. In roots it is made of only one kind of tissue i.e. xylem or phloem.

(a) **Xylem**—It conducts water and minerals absorbed by the roots to the various regions of the plant body. In the vascular bundles it lies towards the centre. It is composed of vessels, tracheids, wood parenchyma and wood fibres. Vessels may be of various types such as annular, spiral, scalariform, reticulate or pitted. Some of the tracheids are found associated with the xylem. The first formed xylem lies towards the centre of the stem and is called protoxylem. It consists of vessels with smaller cavities having annular, spiral and scalariform thickenings. The xylem formed later on lies away from the centre and is called metaxylem. It consists of scalariform, reticulate and pitted vessels with large cavities. This condition of xylem is known as endarch or centrifugal while in roots it is exarch or centripetal i.e. the metaxylem lies towards the centre.

Xylem parenchyma is the only living tissue of the xylem. Rest of the elements of xylem are dead and lignified. It helps in the conduction of water and minerals and also serves as a food storage organ. Wood fibres assist in providing the rigidity and mechanical strength to the xylem.
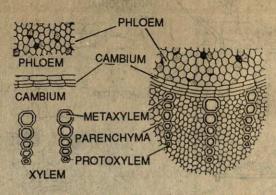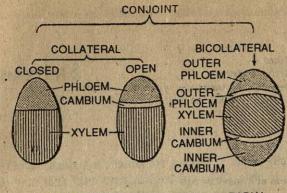
Fig. 2.33 Elements of a vascular bundle (sunflower stem) in T.S.

(b) **Phloem**—It helps in the translocation of the synthesized food from the leaves to the storage organs, growing and other regions of the plant body. It lies above the xylem and towards the circumference. It consists of sieve tubes, companion cells and phloem parenchyma. The first formed phloem consists of narrow sieve-tubes and lies towards the outer portion. It is called protophloem. The latter formed phloem consists of bigger sieve-tubes and lies towards the centre. It is known as metaphloem. All the elements of phloem are living and the cell walls are made up of cellulose.

(c) **Cambium**—It is a thin strip of thin-walled rectangular cells. The cambial cells are primary meristems and lie in between xylem and phloem.

Types of vascular bundles—According to the arrangement of xylem and phloem, the vascular bundles are classified as follows :-

(a) **Radial**—In this type of arrangement xylem and phloem form separate bundles and alternating with each other i.e. they lie on different radii. These bundles are often separated by connective tissue. This type of arrangement is a characteristic of roots.

(b) **Conjoint**—When xylem and phloem combine into one bundle, it is known as conjoint bundle. These are of following types :—

(1) **Collateral**—When xylem and phloem combine together and lie on the same radius, it is known as collateral. In such an arrangement xylem occupies the internal position and phloem the external position. When cambium is present in such a bundle, it is said to be open as in dicot
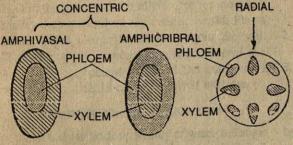
Fig. 2.34 Various types of vascular bundles.

stems, and when the cambium is absent the bundle is said to be closed as in monocot stems.

(ii) **Bicollateral**—In this case, phloem and cambium lie on both sides of xylem. The sequence of the arrangement of tissues in the bundle is as follows : outer phloem, outer cambium, xylem, inner cambium and inner phloem. Bicollateral bundle is the characteristic of the members of *Cucurbitaceae* family.

(iii) **Concentric**—In this type, the xylem and phloem lie concentrically *i.e.* one surrounds the other completely. When xylem lies in the centre and is completely surrounded by the phloem it is known as *amphicribal e.g.* ferns. In some monocot stems, phloem lies in the centre and is completely surrounded by the xylem ; it is known as *amphivasal*.

QUESTIONS
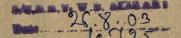
1. What are meristems? What is their role in plants?
2. Name different types of meristems occurring in the plant body.
3. What are the changes that occur in the apex at the time of flowering?
4. Describe the organisation and regions of activity in the shoot apex.
5. What is the quiscent centre? Where is it located?
6. Distinguish between the shoot apex and the root apex.
7. Discuss the role of promeristem and primary meristem.
8. Where would you find intercalary meristems.
9. Draw and label the root apex and shoot apex.
10. Describe the meristems on the basis of their functions.

11. Fill in the blanks —
    (i) Tissues are primarily of two types .... and ....
    (ii) Young cells which lead to the formation of new cells are called ....
    (iii) Central region above root apex with low mitotic activity is called the ....
    (iv) According to their origin and development, the meristems are of three types —promeristems, ... and secondary meristem.
    (v) According to their location, the meristems are of three types ...., intercalary, and ....
    (vi) Based on functions the meristems are protoderm, ..., and ....

12. Explain the following terms —
    (i) Dermatogen, (ii) Periblem, (iii) Latex Vessels, (iv) Xylem.
13. Differentiate between the following —
    (i) Amphivasal and amphicribal
    (ii) Collateral and bicollateral vascular bundles
    (iii) Parenchyma, sclerenchyma and collenchyma
    (iv) Passage cells and endodermis
    (v) Tracheids and vessels.

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(vi) Parenchyma and cambium.
14. In which part of the plant are the following tissues found —
(i) Companion cells, (ii) Periblem, (iii) Latex Vessels, (iv) Hydathode.
15. What do you understand by ground tissue system? Describe the ground tissue system in a dicot stem.
16. What is meristematic tissue? How are they divided on the basis of their position? Draw a well labelled diagram of apical meristem.
17. Differentiate between the following —
(a) Parenchyma and sclerenchyma
(b) Cambium and phloem.
(c) Laticiferous cell and laticiferous vessel.
18. What is a vascular bundle? Describe the different forms of it with drawings.

CHAPTER 3

Mineral Nutrition in Plants

Green plants are autotrophic since they manufacture their own organic food from CO_2 and H_2O in the presence of sunlight. But for inorganic matter they depend on the outside world. Plants obtain these inorganic elements from the soil. These inorganic elements are called *mineral elements* or *mineral nutrients* and the nutrition of mineral nutrients is called *mineral nutrient.*

COMPOSITION OF PLANT ASH

Plant body is made up mainly of water and some solid substances. Uproot a plant and weight it. It is the *fresh weight* of the plant. Dry the plant at 110°C and weigh it to get the dry weight. Take any dry part of the plant in a crucible and heat it at 600°C. The organic matter dissociates into H_2O, CO_2, SO_2, nitrogen oxides, NH_3, CH_3, etc. in the form of vapours. The ash left behind contains minerals and is called *plant ash.* Approximately 60 different minerals have been reported from plants. Of these 30 are present in all plants and the rest may be present in some plants or the other.

Essential and Non-essential Elements

Of the 30 elements universally present in all plants, 16 are essential and the rest non-essential. The essential mineral elements are carbon, oxygen, hydrogen, sulphur, nitrogen, phosphorus, potassium, magnesium, calcium, iron, copper, boron, zinc, manganese, molybdenum and chlorine.

Criteria of Essentiality of Elements

The roots of green plants absorb 30 to 40 elements from the soil. But only a few of them are essential for plant growth and development.

ARNON gave following criteria for the essentiality of an element :—

1. The element must be absolutely necessary for supporting normal growth of the plant and its reproduction.
2. The requirement of the element must be specific and not replaceable by another element.
3. The element must play a direct role in the metabolism of the plant.

Essential elements are divided into two categories based on the quantity in which they are required by the plants—*macroelements* or *macronutrients* and *microelements* or *micronutrients.*

(a) **Macroelements or macronutrients**—These are required by the plant in larger quantities. These are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium and iron.

(b) **Microelements or micronutrients**—These are required by the plant in traces *i.e.* often less than 1 ppm. These are manganese, copper, molybdenum, zinc boron and chlorine. Recent research has shown that elements like cobalt, vanadium, silicon and nickel may be essential for certain plants.

Sources of Essential Elements for Plants

Plants derive all the necessary elements from the atmosphere, soil and water. Carbon enters a plant as atmospheric carbon dioxide. The source of hydrogen is water and oxygen from the air or from water.

Atmospheric nitrogen is inert and most plants are unable to use it. Due to environmental disturbances, nitrogen combines with oxygen and is brought down by rain to the soil. Certain specialized organisms called the *nitrogen fixers* occur in the soil. They convert nitrogen gas (N_2) to

nitrate (NO_3) or nitrite (NO_2) or reduced form such as ammonium (NH_4). These compounds are absorbed by the plants as nutrients through the root and are assimilated as organic nitrogen. All other inorganic elements required by plants are absorbed from the soil, which are ultimately derived from the parent rocks by weathering. Hence, these inorganic elements are called mineral elements. Non-mineral elements are oxygen, hydrogen and carbon.

Importance of Different Mineral Elements in Plants

The study of the importance of mineral nutrients required by the plants and the effects of the deficiency of any one of them is done with the help of *water culture* or *sand culture experiments*. In water culture experiments plants are grown in containers containing a solution of different mineral nutrients in the required proportion. In sand culture experiments, pure sand moistened with the culture solution is used. Typical culture solutions recommended by SACH and KNOP are as follows :—

Knop's Culture Solution		Sach's Culture Solution	
Calcium nitrate	1.0 gm	Calcium Sulphate	0.25 gm
Potassium nitrate	0.2 gm	Calcium Phosphate	0.25 gm
Potassium dihydrogen phosphate	0.2 gm	Magnesium Sulphate	0.2 gm
Magnesium Sulphate	0.25 gm	Sodium Chloride	0.08 gm
Ferric Chloride	traces	Potassium Nitrate	0.70 gm
Distilled Water	1 litre	Ferric Chloride	0.005 gm
	(1000 cc)	Distilled Water	1,000 cc
			(1 litre)
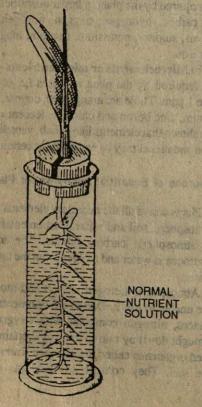
Fig. 3.1 Knop's culture experiment.

To study the effect of the deficiency of an element, that particular element is omitted from the standard culture solution and the plant is grown in it. It is compared with the control plant grown in the *Sachs* or *Knop* culture solution. Now the deficiency effects were noted. Such deficiency effects are called *hunger signs*.

Hunger signs are visible in the large scale farming where the soil is lacking in a particular nutrient. Based on the hunger signs, the deficiency is removed by supplying the missing nutrient.

Experiment—As shown in the figure, take a number of wide-mouthed bottles each fitted with split cork having holes for the insertion of seedlings. Clean these jars thoroughly. Fill one of them with the normal culture solution and the rest with the culture solutions of known composition. Mark the bottles A, B, C, D, etc.

Take seedlings of the same kind and more or less of the same size. Introduce a seedling in each bottle through the split cork. Wrap the bottles with black paper and expose them to light. Make arrangement for proper aeration of roots. Renew the culture solution fortnightly. The following table shows the nature of the solutions used and the effect produced on the seedlings.

CONTROL   -Mg   -Ca   -Fe   -K   —P   -N
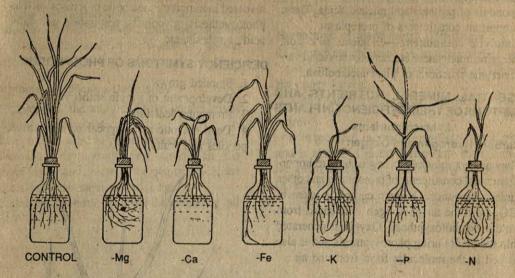
Fig. 3.2 The effects of the deficiency of various mineral nutrients in barley plants grown in water culture.

Solution used	Observations
1. With normal culture solution	Growth of the seedling normal with bright green leaves.
2. Solution lacking magnesium salts	Chlorophyll not formed, carbohydrate formation slow and stunted growth.
3. Solution lacking calcium salts	Root system does not develop properly; leaves spotted, deformed and yellowish; seedling becomes short and weak.
4. Solution lacking iron salts	Seedling becomes yellowish, a condition known as chloisis.
5. Solution lacking potassium salts	Growth becomes checked, carbohydrates formation is reduced, leaves become white and finally plant dies.
6. Solution lacking phosphorous salts	Seedling with weak roots and the growth is slow.
7. Solution lacking nitrogen salts	Unhealthy seedling with weak and yellow leaves.
8. Solution lacking sulphur compounds	Leaves yellowish and stem slender and weak.

Hydroponics

Large scale cultivation of plants in water culture is called *hydroponics*. Some vegetable and ornamental plants like tomatoes, carrots and roses are grown by hydroponics. When plants are grown by this method, they are supported in shallow tanks of nutrient solution with their roots dipped in. Plants may also be grown in sand moistened by frequent applications of nutrient solutions.

MACRO AND MICRONUTRIENTS — ROLE OF MINERALS

Broadly speaking following roles are described to the mineral elements —

1. Components of plant body—Elements like carbon, hydrogen and oxygen enter into the constitution of plant body, cell wall and protoplasm etc. Bulk of the plant body is composed of these elements. These elements are the constituents of a large number of compounds such as carbohydrates, fats, proteins, cellulose etc. As calcium pectate, calcium is an important constituent of cell wall and magnesium of chlorophyll.

2. Components of protoplast—Elements like

sulphur, phosphorus and nitrogen are the essential components of proteins and nucleic acids. These are important constituents of protoplasm.

3. Catalytic components—Elements like iron, copper, zinc, manganese etc. act as catalysts in various enzyme reactions of plant metabolism.

ESSENTIAL MINERAL NUTRIENTS AND SYMPTOMS OF THEIR DEFICIENCY IN PLANTS

(A) Macronutrients

1. Carbon, Hydrogen and Oxygen

They are not minerals in origin, but are important structural constituents of protoplasm and other organic compounds. Of them carbon is taken in as CO_2 from the air. Hydrogen is released from water during photosynthesis. Oxygen is generated within the plant during photosynthesis and is also absorbed in the molecular form from the air.

2. Nitrogen

Excepting the nitrogen fixing organisms (certain bacteria and blue-green algae), plants obtain their nitrogen requirements from soluble nitrates in the soil.

Nitrogen is an important component of protoplasm. It is also present in important compounds like amides, alkaloides, purines, pyrimidines, porphyrins and enzymes. Nitrogenous compounds play a major role in protein synthesis. The genetic material, DNA, contains nitrogenous bases, purines and pyrimidines.

SYMPTOMS OF NITROGEN DEFICIENCY

1. Yellowing of leaves, *i.e. chlorosis,* due to decrease in chlorophyll content. The symptom makes its appearance first in mature leaves and thin in young leaves.
2. Nitrogen deficient plants show purplish colouration due to the synthesis of *anthocyanin* in place of chlorophyll.

Excess of nitrogen causes excessive growth of leaves which are dark-green in colour. Excessive nitrogen reduces the root system and delays flowering and seed formation. Plants become easily susceptible to the attacks of fungi and insects in the excess of nitrogen.

3. Phosphorus

It is an important constituent of nucleic acids, phospholipids, ATP, NAD and NADP. It is involved in important metabolic processes such as photosynthesis, glycolysis, respiration and fatty acid synthesis, etc.

DEFICIENCY SYMPTOMS OF PHOSPHORUS

1. Stunded growth.
2. Development of purple anthocyanin.
3. Premature leaf fall.
4. Dead necrotic areas appear on the leaves, petioles and fruits.
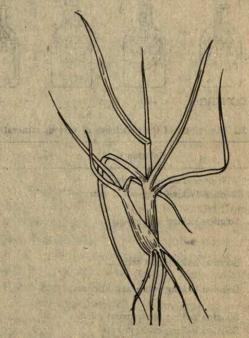
Fig. 3.3 Young wheat plant showing nitrogen deficiency.

4. Potassium

Potassium is essential for protein synthesis, photosynthesis, respiration and stomatal movements.

SYMPTOMS OF POTASSIUM DEFICIENCY

1. Stunted growth.
2. Mottled chlorosis followed by necrotic shrivelling of the margins of the leaves.
3. In some cereals, the potassium deficiency leads to the developemnt of weak stalks.

5. Calcium

Calcium is absorbed from the soil in the form

of calcium ions. It is a constituent of cell wall in the form of calcium pectinate. It plays an important role in lipid metabolism. It is required for cell division and cell enlargement, in the translocation of carbohydrates and an activator of several enzymes.

Symptoms of Calcium Deficiency

1. Chlorosis of the margins of the young leaves leading to their necrosis.
2. Leaf tips of several plants become hooked.
3. Deficiency symptoms first appear in the younger leaves and apices of the plants and causes the death of leaf, stem and root apices.
4. Supresses flowering or causes the premature fall of leaves.

metabolism, and those involved in the synthesis of RNA and DNA. It is also essential for the binding of the components of ribosomes.

Symptoms of Magnesium Deficiency

1. Interveinal chlorosis (yellowing) of the leaves. Yellowing appears first in the lower and then in the upper leaves.
2. Chlorosis is followed by necrosis.

7. Iron

It is required in small quantities by the plants and is absorbed in the ferric state though inside the plant body it is metabolically active in the ferrous state.

Inside the plant body, it is essential for the syn-
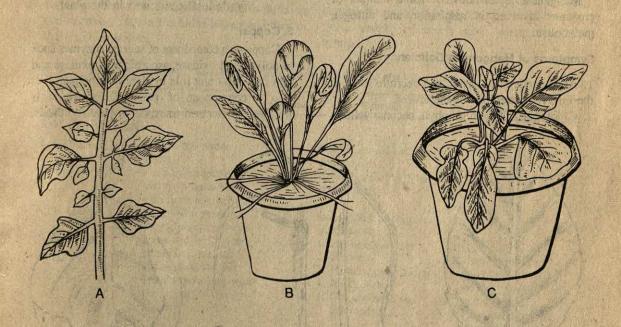
Fig. 3.4 (A) Tomato leaf showing potassium deficiency.
(B) Sugar beet plant showing calcium deficiency.
(C) Radish plant showing magnesium deficiency.

6. Magnesium

Magnesium is a constituent element of chlorophyll. It also acts as an activator of some enzymes especially those concerned with carbohydrate

thesis of chlorophyll. It also affects the formation of carotenoids. It takes part in the composition of cytochromes, and ferredoxin compounds which take part in the electron transport system in plants.

Deficiency of iron results in interveinal chlorosis in the younger leaves.

8. Sulphur

Sulphur is a constituent of three amino acids—cystine, cysteine and methionine which take part in the composition of several proteins. It is also present in coenzyme A and in the vitamins—biotin and thiamine. Sulphur increases the root development and increases in the nodule formation in legumes.

Symptoms of Sulphur Deficiency

Deficiency of sulphur results in *chlorosis*. The yellowing first appear in young leaves. In some cases, all the leaves show chlorosis at the same time.

(B) MICRONUTRIENTS

1. Manganese

Manganese is an activator for a number of enzymes involved in respiration and nitrogen metabolism.

Symptoms of Manganese Deficiency

1. Appearance of chlorotic and necrotic spots in the interveinal regions of the leaves.
2. Chloroplasts lose chlorophyll, become yellowish in colour and finally disintegrate.

2. Zinc

Zinc is essential for the synthesis of indole-acetic acid (IAA), a plant growth substance. It also serves as an activator for several enzymes such as alcohol dehydrogenase, lactic dehydrogenase, glutamic acid dehydrogenase and carboxypeptidases.

Deficiency Symptoms of Zinc

1. Stunted growth with reduction in the size of the internodes.
2. Interveinal chlorosis of leaves starting at the tips and margins in the first stage and white necrotic spots in the second stage.
3. Deficiency of zinc decreases the IAA content in plants thereby causing a reduction in the growth. It results in 'little leaf' and 'mottle leaf' conditions in the plants.

3. Copper

Copper is a component of several enzymes such as polyphenol oxidase, ascorbic acid oxidase and plays an important role in plant metabolism. It is also a component of plastocyanin which is involved in electron transport in photosynthesis.

A   B   C
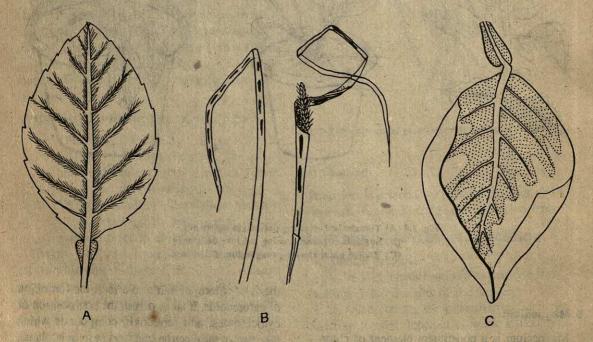
Fig. 3.5 (A) Manganese deficiency in a lemon leaf, (B) Copper deficiency in wheat, (C) Lemon leaf showing curled margins and necrosis due to molybdenum deficiency.

Symptoms of Copper Deficiency

1. It's deficiency reduces the CO_2 absorption.
2. Young leaves exhibit necrosis at the tip, and then in the margins, resulting in the withered appearance.
3. Its deficiency in citrus trees causes *exanthema* and in cereals and herbaceous legumes, a disease known as the *reclamation disease*.

4. Molybdenum

Molybdenum plays an important role in the nitrogen metabolism of plants. It is a constituent of the enzyme reductase. It also takes part in the phosphorous and ascorbic acid metabolism of the plant.

Symptoms of Molybdenum Deficiency

1. Deficiency of molybdenum results in mottling and necrosis, first in the older leaves and then in the younger leaves.

2. In cauliflower, the expansion of leaf-lamina is suppressed resulting in the *'whip tail'* condition.
3. Results in the abscission of flowers.

5. Boron

Boron is involved in the translocation of carbohydrates. It increases the absorption of water and calcium and takes part in the formation of pectin in the walls.

Deficiency Symptoms of Boron

1. Death of the stem and root apices.
2. Leaves exhibit thick texture, curl and become brittle. Sometimes the leaf tips become black.
3. Deficiency also leads to meagre production of flowers.
4. Causes disintegration of the internal tissues, causing 'heart rot' of beets, *'drought rot'* of apples, *'stem crack'* of celery and *'water core'* of turnip.

Table : 3.1 Amount of essential and their role in rooted green plants.

Name of Element	Source	Quantity	Functions	Deficiency Symptoms
MACRONUTRIENTS				
1. Carbon	CO_2 of the atmosphere	45%	Constituent of cellular components	→
2. Oxygen	As a byproduct of photosynthesis and also from atmosphere	43%	Constituent of cellular components	—
3. Hydrogen	Released from water during photosynthesis	6%	Constituent of cellular components	—
4. Nitrogen	(i) From soil in the form of nitrates, nitrites and ammonium salts (ii) From atmosphere with the help of N_2-fixing bacteria.	1-3%	1. All living matter 2. Proteins 3. Purines, pyrimidines 4. NAD, NADP 5. Cytochromes and chlorophyll	1. Chlorosis 2. Development of purplish colour due to the formation of anthocyanins 3. Supressed growth with small leaves, early defoliation 4. Flowering delayed
5. Sulphur	From soil as SO_4 ions	0.05 1.5%	1. All living matter 2. Amino acids, cystine, cysteine methionine 3. Coenzyme A, thiamin and biotin vitamins 4. For chlorophyll synthesis 5. Increases root growth & nodule formation in legume plants	1. Stunted growth 2. Chlorosis first appearing in younger leaves 3. Formation of anthocyanin

Name of Element	Source	Quantity	Functions	Deficiency Symptoms
6. Phosphorous	From soil as phosphate ions	0.05 1.0%	1. Nucleic acids, nucleo-proteins, phospholipids, sugar phosphates 2. Present in AMP, ADP, ATP, GDP, GTP and NADP 3. Plays an important role in energy transfer in photosynthesis and respiration	1. Stunted growth and premature leaf fall 2. Development of anthocyanin pigment 3. Brown necrotic areas appear on leaves, petioles and fruits 4. Restricted growth of root and shoot 5. Poor development of vascular tissue 6. Delayed flowering
7. Calcium	From soil in the form of Ca^{++} ions	1-3.5%	1. As calcium pectiriate for the formation of middle lamella in cell wall 2. For lipid metabolism 3. For cell division & cell enlargement 4. Helps in translocation of carbohydrates 5. Activates enzyme activity	1. Meristematic regions badly affected 2. Chlorosis of margins of young leaves leading to necrosis 3. Flowering suppressed or premature fall of flowers
8. Potassium	From soil in the form of K^+ ions	0.3-6.0%	1. Enzyme system in the change of sugar to starch, amino acids to proteins and respiratory reactions 2. Stomatal movements 3. Reduction of nitrates 4. Permeability of cells	1. Stunted grwoth 2. Mottled chlorosis, necrotic shrivelling of leaves 3. Decrease in apical dominance 4. In cereals-development of weak stem
9. Magnesium	From soil in the form of Mg^{++} ions	0.05-0.07%	1. Constituent of chlorophyll 2. Activator of a number of enzymes of respiration and photosynthesis 3. For binding of ribosomes 4. As a buffer	1. Interveinal chlorosis 2. Formation of anthocyanin pigments 3. Necrosis in severe cases

Micronutrients

Name of Element	Source	Quantity	Functions	Deficiency Symptoms
10. Iron	From soil in the form of ferrous salls	10-1500 ppm	1. For the synthesis of chlorophyll and formation of carotenoids 2. Constituents of cytochromes. Activates a number of enzymes	1. Inter-veinal chlorosis 2. Localized or generalized chlorosis
11. Mangenese	From soil as Mn^{++} ions	5-1500 ppm	1. For chlorophyll synthesis 2. For nitrogen metabolism 3. Activator of arginase, carboxylase, dehydrogenase 4. In the transfer of electrons OH^- ions to photoexcited chlorophyll	1. Chlorotic and necrotic spots in the interveinal regions of leaf 2. Leaves become mottled

Name of Element	Source	Quantity	Functions	Deficiency Symptoms
12. Zinc	From soil as Zn^{++} ions	3-150 ppm	1. For the synthesis of auxins 2. Phosphorylation enzymes 3. Enzymes in chloroplasts	1. Decreased growth 2. Reduction in the size of inter-nodes 3. Mottle leaf condition
13. Boron	From soil as anion borate	2-75 ppm	1. Translocation of enzymes 2. Active salt absorption 3. Flowering and fruiting 4. Phosporylation enzymes	1. Death of stem and root apices 2. Leaves become thick, cruled and brittle 3. Flower production greatly reduced
14. Copper	From soil as cations	2-75 ppm	1. Enzymes in the synthesis of ascorbic acid 2. Activator of poly-phenol oxidase, lactase and oxidases	1. Necrosis in the young leaves at the tips and along the margins 2. Exanthema in citrus tree and reclamation disease in cereals and legumes
15. Molybdenum	Traces from soil as cations		1. Activates nitrate reductase 2. Plays an important role in nitrogen metabolism	1. Mottling and necrosis in older leaves 2. Deficiency causes whip-tail disease in cauliflower
16. Chlorine	From the soil	100-300 p.pm.	In the transfer of electrons from options to photoexcited chlorophyll	—

UPTAKE OF MINERAL NUTRIENTS

Plants take in mineral nutrients, including some which may not be essential to them, through the roots. The process of intake of nutrients from the soil is called mineral absorption. Absorption of minerals by the roots takes place in two ways— (i) *passive absorption* and (ii) *active absorption*.

1. Passive Absorption

Normally, the movement of mineral ions into the roots takes place by *diffusion*. Molecules or ions diffuse from a region of their higher concentration to a region of their lower concentration. As these substances diffuse into the root, they exert a pressure called *diffusion pressure*. The movement of mineral ions into root cells as a result of diffusion is called *passive absorption*.

2. Active Absorption

The uptake of mineral ions against concentration gradient is called active *absorption*. Such movement of minerals requires an expenditure of energy by the absorbing root cells. This energy is supplied through ATP derived from respiration. In the absence of oxygen, roots show a sudden drop in active absorption of minerals. The mineral ions accumulated in the root hairs reach xylem through the cortex. The minerals in the xylem are then carried along with water to other parts of the plant along the transpiration stream. Mineral elements reaching the leaves take part in the assimilation of organic compounds and then transported to other parts of the plant through phloem.

Questions

1. Explain the role of mineral nutrients in the life of a plant.
2. What is meant by plant mineral nutrition ? What elements are important in plant mineral nutrition.
3. What are micronutrients? Comment on the role of micronutrients in plants.
4. Describe the role of any two macronutrients and two micronutrients in the life of a green plant and explain how you detect their deficiency ?
5. Give the composition of any one normal culture solution and why is it used for plants ?
6. List the common symptoms of mineral deficiency and mention the names of the elements, the lack of which produce these symptoms.
7. Write short notes on the following :
    (a) Mineral nutrition
    (b) Hunger signs
    (c) Hydroponics
    (d) Micronutrients
8. What are the differences between macronutrients and micronutrients? Give two examples of each.
9. What is chlorosis?
10. Write the importance of sand culture experiments.
11. Classify the following mineral elements to macro and micronutrients—
    C, Bo, Mn, O, Co, Zn and Cu.
12. Enumerate the main deficiency symptoms of potassium and calcium.
13. What are micronutrients? Name them.
14. Give two deficiency symptoms of each of the following :
    (a) Phosphorous
    (b) Copper
    (c) Magnesium
    (d) Boron.
15. How you will justify the importance of the following as nutrients—
    (a) Manganese
    (b) Sulphur
    (c) Iron.
16. Explain the following :
    (i) Active absorption of minerals.
    (ii) Passive absorption of minerals.

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CHAPTER 4

Modes of Nutrition

Nutrition is one of the important energy for its various life activities. Energy is obtained by the oxidation of different foods. Method of taking in and synthesis of various types of foods by different plants and animals is called *nutrition*.

On the basis of mode of nutrition, plants are classified into the following groups:

A. *Autotrophic Plants*
   (a) Photosynthetic
   (b) Chemosynthetic
B. *Heterotrophic Plants*
   (a) Parasites
   (b) Saprophytes
   (c) Insectivorous
   (d) Symbiotic

A. AUTOTROPHIC PLANTS

Autotrophic plants have the capacity to manufacture their food from inorganic substances. They are of following two types—

(a) Photosynthetic (Photoautotrophic)

These are green plants and some bacteria, which synthesize their food from CO_2 and water in the presence of light. This process is known as photosynthesis.

(b) Chemosynthetic (Chemoautotrophic)

Some bacteria obtain energy by biological oxidation of certain inorganic substances for food synthesis instead of sunlight. Such bacteria are called *chemosynthetic bacteria*. They are of following catgegories—

(i) *Nitrifying bacteria* are of two types. *Nitrosomonas* convert ammonia into nitrite and *Nitrobacter* convert nitrite into nitrate.

(ii) *Iron bacteria* convert ferrous compounds into ferric compounds.

(iii) *Hydrogen bacteria* convert hydrogen into water.

(iv) *Sulphur bacteria* convert hydrogen sulphide into water and sulphur.

B. HETEROTROPHIC PLANTS

Those plants which are not able to synthesize their own food and depend for their food on other plants and animals are called heterotrophic plants. These are of the following types—

(a) Parasites

The plants which obtain their food from other living plants or animals are called *parasites*. The plants or animals on which they feed are known as *hosts*. Many bacteria and fungi are parasitic on plants and animals and are the cause of many diseases. The common plant diseases caused by the parasitic bacteria are *fire blight* of apple and pear, *citrus cancer* and brown rot of potato. The common diseases of animals are *typhoid, cholera, tuberculosis, chicken pox, cholera*, etc.

In parasitic fungi, the mycelium penetrates the tissues with the help of enzymes which dissolve the cell walls of the host and either lives inside the cell or sends special food-absorbing structures called haustoria into the cells of the host. Rust and smut in plants and ring worm in man are caused by parasitic fungi.

A number of following plants also lead a parasitic life. These are of two types :

(a) *Obligate* or *total parasites* and (b) *partial* or *semiparasites*.

(a) Obligate or total parasites—

Such plants take whole of their prepared food from host plants. These plants are without cholorphyll. These plants are of two types (i) *total stem parasites* and (ii) *total root parasites*.
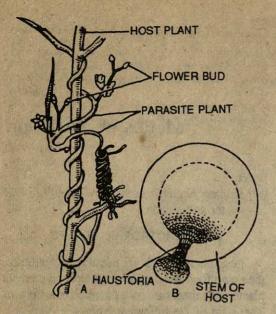
Fig. 4.1 Total stem parasite —Cuscuta with haustoria.

Fig. 4.2. Total root parasite—Orobanche growing on the root of brinjal.

(i) *Total stem parasites-Cuscuta* is a total parasite on *Duranta* and jujube tree. This plant is rootless, yellow coloured, slender stem with small scale leaves twined around the host. At intervals it sends sucking roots or haustoria into the tissue of host plant. Here the xylem and phloem of the parasite make a direct contact with the xylem and phloem of the host and gets its food supply from the host.

(ii) *Total root parasites*—Examples of total root parasites are *Orobanche, Balanophora* and *Rafflesia.*

Orobanche is parasitic on the roots of brinjal and tobacco. It bears scale leaves and pinkish or bluish flowers. The root tip of the parasite makes haustorial contact with the root of host and absorbs food from it.

In *Rafflesia,* vegetative parts of the plant are greatly reduced and are represented by cellular filaments. These filaments get embedded in the soft tissue of the host roots and the flowers emerge out in the form of buds. Rafflesia flowers are largest of all the flowers weighing about 11 kg.

(b) *Partial Parasites—*

They are of the following two types—

(i) Partial stem parasites-*Viscum album* (mistle-

toe) is a common example of stem parasite. It is usually found growing on the branches of oak and walnut trees. *Viscum* plant is dichotomously branched with paired leaves borne on each node of stem. It sends out haustoria here and there on the host plant for its mineral and water supply. *Loranthus* in another example of stem parasite.

(ii) Partial root parasites—*Santalum album*

(sandal wood tree) is an evergreen partial root parasite which grows in South India. Young seedlings of *sialbum* can live and grow independently for one year only. Within this period roots develop haustoria which make contact with the roots of *Dalbergia* and *Eucalyptus* to absorb minerals and water.

(b) Saprophytic Plants

Saprophytes grow on dead and decaying organic matter of animals and plants. Several fungi and bacteria have saprophytic mode of nutrition. Saprophytes are of great economic importance because they break complex organic substances into simpler ones. Souring of milk, formation of curd and vinegar are examples of the activity of saprophytic bacteria. Yeast, *Mucor, Penicillium* and *Agar-*

...icus are the examples of saprophytic fungi.
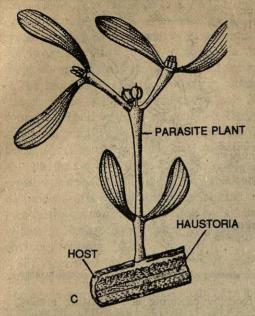
Fig. 4.3 Partial parasites—Viscum plant attached to the host stem.
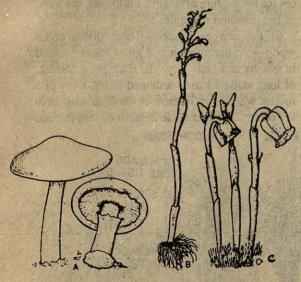
Fig. 4.4 Saprophytic plants (A) Agaricus; (B) Nepottia; (C) Monotrapa (a fungus) (Birds nest) (Indian pipe).

Among angiosperms *Neottia* and *Monotrapa* are the examples of saprophytes. *Neottia* grows on soil rich in humus. It has a underground stem with a cluster of roots. The roots are associated with endotrophic mycorrhiza. Fungus absorbs its food from the humus. Cortical cells of the roots of *Neottia*

absorb the food from the fungus. Infact Neottia is a parasite on fungus. It produces fleshy and light brown aerial shoots. Stem bears brown scale leaves and a spike of orange coloured flowers.
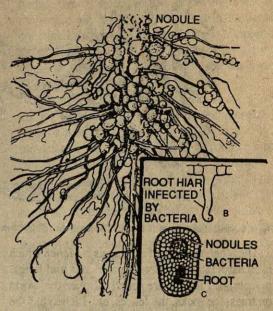
Fig. 4.5 Root nodules of pea.

Monotrapa is found in pine forests growing on soil rich in humus. Its aerial parts are without chlorophyll. Its underground parts are also associated with endotrophic mycorrhiza (fungi) and absorbs food like *Neottia*.

(c) Symbiotic plants

The majority of plants are unable to use the atmospheric nitrogen. But the plants belonging to the family Leguminosae indirectly make use of the atmospheric nitrogen. The roots of these plants are nodulated bearing swollen structures or nodules. These are the thickenings of the cortex owing to the presence of bacteria known as *Bacillus radicicola*. These bacteria change and fix the gaseous nitrogen in the form in which it is utilized by the plants. In this round about way, the bacteria break down some of the carbohydrates and use the kinetic energy for their metabolic activities and the plants use some of the broken down bacteria as their food material. This relationship of the bacterium with the roots of the leguminosae is known as *symbiosis*, as both organisms derive benefit and neither is weakened, the plants getting the benefit of the nitrogen compounds and the bacteria getting the supply of carbohydrates.
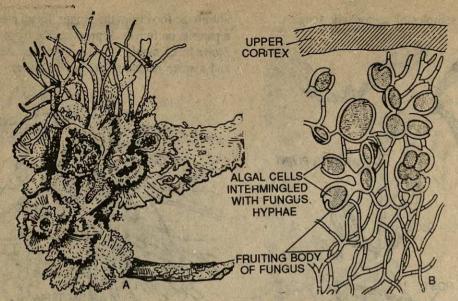
Fig. 4.6 Symbiotic plants (Lichens) (A) Lichen; (B) Section of lichen showing algal cells embedded in fungal mycelia.

The other example of symbiosis is *Lichen* which is an association between a green alga and fungal mycelium. Lichens are found all over the world on trees, the rocks, the fences, etc. Lichen has the form of a flattened more or less rounded and lobed thallus. **The alga provides food and fungus provides water minerals and protection to the alga.**

(d) Insectivorous Plants

Certain flowering plants growing in swampy and water-logged land where there is a deficiency of nitrogen, supplement their supply of nitrogen-ous food by capturing and digesting insects, although chief mode of nutrition is photosynthe-tic. The insectivorous plants show beautiful devi-ces for the capture of insects. Following are some of the common examples :

(i) *Drosera or sundew*—These plants enjoy world-wide distribution and grow lossely rooted in marshy and petty grounds. Each plant consists of long stalked leaves arranged in the form of a rosette with the inflorescence shoot arising from the centre. The leaf blade is more or less circular
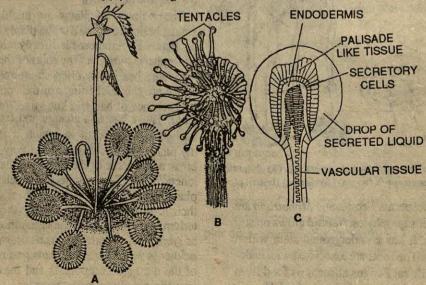
Fig. 4.7 Insectovorous plant Drosera.

with edges and the upper surface covered with long, club-shaped and reddish tentacles. On an average, there are about two hundred tentacles. The apical swelling of each tentacle secrets a sticky digestive fluid, which glistens in the sun like dew drop, whence, the name sundew for this plant.

The secreted fluid which is sugary attracts insects. When an insect alights on a leaf, it is detained and held by the viscid secretion. The tentacles are sensitive to touch, and the stimulus brings about a curving of the tentacles with the insect to the centre of the leaf. The secreted fluid contains an enzyme which digests the proteins and the products of digestion are absorbed by the leaf. Finally, the tentacles open and come back to their original position thereby releasing the indigestible chitinous remains.

(ii) *Nepenthes or pitcher plant—Nepenthes* affords a very good example of the pitcher plants. The whole or a part of the leaf is modified to form a pitcher and the petiole takes the form of leaf and carries the photosynthetic function of the lamina. In most cases pitchers have bright colours to attract the insects and are provided with lid or operculum. The edge of the pitcher has a rounded rib of vascular bundles, thus forming a rim. The rim is also brightly coloured and bears a large number of honey glands.

The insects are attracted by the brilliant colour of the pitcher and the sugary fluid secreted by the rim. As the insect alights on the rim of the pitcher and tries to reach the sugary fluid just inside, it slips down and falls into the liquid contained by the pitcher. The presence of downwardly pointed hairs prevents the insect from crawling up. Thus the insect ultimately gets drowned in the liquid contained, is digested by its *proteolytic* enzymes and is finally absorbed by the walls of the pitcher. In this way plant obtains nitrogen from the bodies of the entrapped insects.

(iii) *Utricularia* or *Bladderwort*—It is a well known insectivorous plant found submerged in streams and ponds. The leaves are highly segmented and some of these segments become modified into bladders. Each bladder is a small, oval and stalked structure lined with glands and is provided with a valve which opens inwards. The inner walls of the bladder are provided with glandular hairs. These hairs have the ability of absorbing some of the contained water and in doing so they cause a partial vacuum inside the bladder which keeps the two side walls of the bladder slightly pulled in. When an unwary insect touches the hairs on the outer side of the valve, it is pushed in and the insect along with water is also sucked in. The valve again returns to its normal position. The imprisoned insect is digested by the proteolytic enzymes and is finally absorbed.

Fig. 4.8 Nepenthes (pitcher plant).
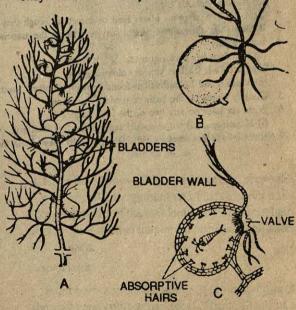
Fig. 4.9 Utricularia or bladderwort (A) Submerged portion of the plant (B) A single bladder (magnified), (C) Section of a bladder.

(iv) *Dionaea or the 'Venus fly trap'*—Dionaea is a native of U.S.A. found in marshy places. It consists of a rosette of leaves. Each leaf represents a fly trap and consists of a broadly flattened petiole constricted off from the lamina. The lamina is beautifully coloured roundish structure having digestive glands on the dorsal surface. It can fold along the mid-rib and its each half is provided with three 'tigger hairs'. The hairs are sensitive to touch.

While visiting the plant, if any insect happens to touch the sensory hairs of the leaf blade, it brings about the sudden closure of the leaf-blade. The digestive glands pour the enzyme *pepsin* and *hydrochloric acid* and bring about the digestion of proteins present in the body of insect.
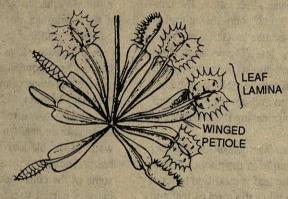
Fig. 4.10 Dionaea (Venus fly trap).

QUESTIONS

1. Write notes on the following :
   (a) Insectivorous plants
   (b) Parasite
   (c) Symbiosis
   (d) Chemosynthesis
2. Explain—Insectivorous plants feed on insects although they have chlorophyll.
3. Rafflesia and Orobanche cannot survive without the association with other plants. Explain.
4. Explain why—
   (a) Santalum has suctorial roots.
   (b) Cuscuta is leafless yellow coloured plant
   (c) Viscum and Loranthus are found growing on other plants although they have green colour.
5. Classify plants on the basis of mode of nutrition.
6. Write six lines on any two of the following :
   (i) Monotropa, (ii) parasite, (iii) saprophyte, (iv) Rafflesia, (v) Utricularia.
7. Name two insectivorous plants. Describe how they obtain their nutrition.

CHAPTER 5

Transport of Solutes and Water

The water present in the soil is in the following three conditions—

1. Hygroscopic water—The soil particles are surrounded by a film of water called the hygroscopic water. This water is not available to the plant as it is not free but remains around the soil particles due to hygroscopic action.

2. Gravitational or free water—When water enters the soil from the surface either by irrigation or rain, it passes through the spaces between the soil particles and reaches the water table. This is called *gravitational water*. It is not available to plants because it lies far below the reach of the roots.

3. Capillary water—This is the only water available to the plants. This water is held in between the soil particles by the capillary force. It also contains a number of mineral salts in the solution.

In addition to capillary water, the soil particles are covered by a thin film of water called *hygroscopic water*. This water is held by forces of attraction between the soil particles and water molecules. This greatly reduces water potential. As a consequence, hygroscopic water is not available to plants.

ABSORPTION OF WATER BY PLANTS

It has been shown that water can enter plants through its entire surface *i.e.* leaves, stem and roots. However, the bulk of water is absorbed by land plants through the roots.

Root System as Related to Water Absorption

Roots absorb water and minerals mainly from the terminal portions. Roots are extensively branched so that there are millions of root tips on a root system of a mature plant. A root tip has the following distinct zones—

1. Root cap—It is presnet at the apex of the root as a protective tissue.

2. Meristematic region—It is the region of cell division situated below the root cap.

3. Region of cell enlargement—It is situated above the meristematic region. In this region growth and enlargement of cells takes place.
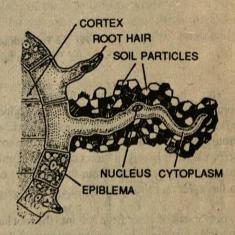
Fig. 5.1 Diagrammatic representation of the relation of root hair to the soil.

4. Root-hair zone—This zone is located above the region of cell enlargement and bears slender hair-like outgrowths of the epiblema called the root hair. It is in this zone that maximum abrosption of water takes place.

Root Hairs

Root hairs are delicate tubular prolongations of the epiblema (piliferous layer). The cell wall of a root hair is made up of two layers. The outer layer

is made up of pectic compounds. The inner layer is made up of cellulose. The cell wall acts as a permeable membrane. Next to cell wall is a plasma membrane. It encloses cytoplasm, nucleus and vacuole. Vacuole is quite large in size and contains cell sap. Plasma membrane acts as a semi-permeable membrane.

Mechanism of Absorption of Water

Root hairs provide a large surface for water absorption.

Demonstration of root-pressure—Cut across the stem of a healthy herbaceous potted plant a few inches above the ground particularly in the morning. Attach a close-fitting rubber tube and insert a tight-fitting glass tube to the other end of the tube. Connect a manometer partially filled with coloured water to the tube through a rubber cork. Fill the
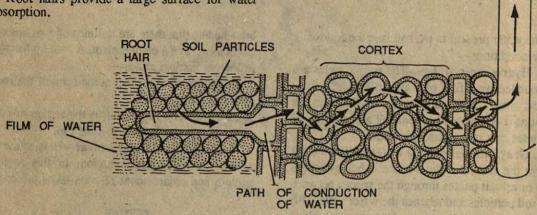
Fig. 5.2 The path of water from soil into the root arrows indicate the direction at the movement of water

The hair cells are followed by the cortex and endodermis. Internal to the endodermis is a single layer of parenchymatous pericycle. Protoxylem elements of xylem lie opposite to the pericycle. In this way, a direct channel is formed for the passage of water from the root hair cells to the xylem as shown in the diagram.

Movement of water from soil into the root hairs, and from them in to cells of the xylem with lower water potentials, results in *root pressure* which pushes the water up the xylem vessels.

Root Pressure

Root pressure is the pressure set up by the cortical cells of the roots upon their liquid contents under fully turgid conditions forcing a quantity of it into the xylem vessels and through their upwards into the stem is called the root pressure. Root pressure may also be defined as the pressure under which water passes from the living cells of the root into xylem absorption.
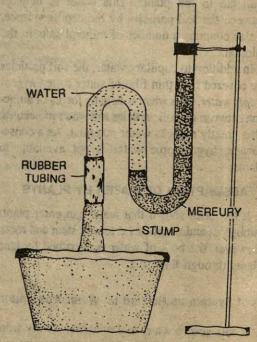
Fig. 5.3 Experiment to demonstrate root pressure.

T-tube with coloured water and pour some water in the pot. Insert a cork in the upper open end of the water-filled T-tube and make all the connections air-tight by applying molten paraffin wax. To start with, note the level of water in the long arm of the manometer.
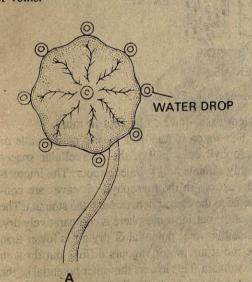
After a few hours, it will be noted that the water level has gone up in the long arm of the manometer. This rise of water is due to the accumulation of water in the T-tube due to the exudation of water from the cut surface of the stem is due to the root pressure. The root pressure can be measured by the difference of level of water in the manometer before and after the experiment. Pressures up to 5 atmospheres have been recorded by this method.

Guttation—In herbaceous plants when root-pressure is high and transpiration is low, the water is forced out in the form of drops from the margins or tips of leaves. This process is called *guttation*. Guttation is seen occurring at night in herbaceous plants growing under conditions of high soil moisture and high humidity.

Guttation takes place through specialised pores called *hydathodes*. These are situated at the ends of veins.

stem to its leaves, flowers and other parts of plant is known as *ascent of sap*. The elongated, lignified tracheids and xylem vessels placed end to end, without any cross walls form the pipe-line for conducting water and minerals in vertical direction from root to leaves.

Path of water-particle—Water enters the root hair cell firstly by imbibition and then by the process of osmosis. The water from the root hair cell passes into the xylem vessels through the cells of the cortex and endodermis. The ascent of sap from the roots, in stem and then to leaf veins through vessels and tracheids, is by means of the pull exerted by the leaf cells at the top of the sap column. The cohesion of water molecules to one another gives the necessary continuity of the column. In the leaf-blade water passes from the xylem into the cells of the mesophyll and epidermis. This takes place by osmosis as a result of suction pressure gradient. A part of this water saturates the walls of these cells from where it is evaporated into the intercellular spaces. From intercellular spaces water diffuses into the atmosphere through the stomata.
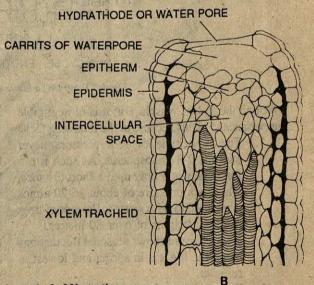
Fig. 5.4 A. Guttation in the leaf of Nasturtism.
B. Section of leaf through a hydrathrode.

Ascent of Sap

The upward movement of water and mineral salts in the lumen of xylem vessels through the

Root pressure under certain conditions exudates water from cut stems. This prompted the veins that root pressure causes the movement of water
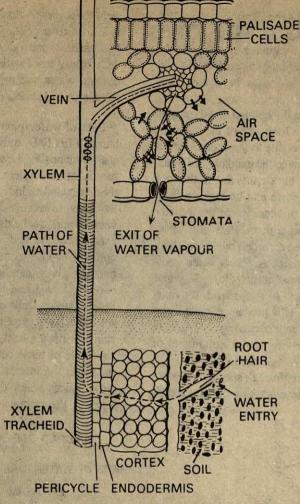
Fig. 5.5 Diagram to illustrate conduction of water.

through the xylem vessels. But it is of negligible importance to plants because of the following facts:

1. The magnitude of root pressure never exceeds 2-3 atmospheres. As such it can force the water only upto a short distance, whereas a pressure of about 16-20 atmos is required to raise water to the tops of trees reaching heights of over 80 metres.

2. Root pressure shows seasonal fluctuations being the highest in spring and lowest in summer.

3. Water continues to rise even in the absence of root pressure.

4. No root pressure has been observed in Gymnosperms.

While explaining the ascent of water in the plants, several physical phenomena, the chemical nature of plant cell walls and the structure of the xylem tissue have to be kept in mind.

The water vapour lost by the moist walls of mesophyll cells makes the intercellular spaces highly saturated with water vapour. The intercellular spaces in the mesophyll of leaves are connected to the atmosphere through the stomata. The air of the outside atmosphere is comparatively dry. Since the water potential of dry air is lower than the moist air, water vapours diffuse out through the stomata. This lowers the water potential of the surrounding mesophyll cells. Thus they draw water from the cells in the deeper tissues of the leaf. During transpiration, water is drawn continuously from the leaves along the xylem of the stem and the root tips in contact with soil water to create a *transpiration pull.*

The walls of xylem vessels are made of *lignocellulose.* It has a great affinity for water mole-

cules. The adhesion of water molecules to the xylem vessels and cohesion of water molecules among themselves form a thin, unbroken column of water in the capillaries of xylem vessles. When the transpiration pull is exerted, a negative pressure or tension is transmitted down to the roots. This tension causes a decrease in water potential. Lowered water potential encourages uptake of water by roots.

The above mechanism clearly explains the lifting of water to the tops of the tallest trees. The water potential in the leaves borne on tree tops has been found to be as low as-30 bars. Such a low water potential is sufficient to overcome gravitational pull and resistance offered by the capillaries of the xylem vessels.
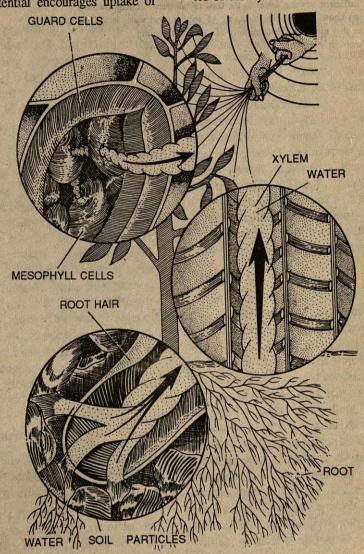
Fig. 5.6 Ascent of sap in tall plants.

QUESTIONS

1. Differentiate between gravitational, capillary and hygroscopic water.
2. How does a root hair absorb water from the soil ?

3. Distinguish between active and passive absorption of water.
4. Define root pressure.
5. How will you demonstrate root pressure ?
6. What are the two kinds of interactions of water molecules that allow water to travel upward in plants ? What other physical process aids in water transport to tops of trees ?
7. Which of the following has the highest water potential (a) IM salt solution, (b) IM sugar solution, (c) distilled water, (d) IM sugar solution with 2.3 bars pressure applied to it ?
8. What forces are involved in the absorption of water from the soil by root hairs ?
9. The water potential of pure water is ....
10. Root pressure is sufficient to raise water to the tops of tall trees. .... Right/wrong.
11. What is our present knowledge relating to ascent of solutes and water in tall plants?
12. Mention the forces that maintain the continuity of the water column.
13. Name the tissue through which ascent of sap takes place.

CHAPTER 6

Plants absorb a large quantity of water from the soil. Only a small part of it (1-2%) is utilized by the plant for the building up processes, while bulk of the water (98-99%) is lost into the air from the leaves and other aerial parts of the plant.

This loss of water in the form of vapours from the aerial parts of the plant is known as *transpiration.*

Thus transpiration may be defined as the *loss of water vapour from the aerial parts of a living plant viz., leaves, green shoots etc.*

The amount of water lost by transpiration is considerable. It has been calculated that 6000 maize plants growing in an acre of land transpire more than 13,00,000 litres of water during one growing season. Plants retain only a small portion of water that is absorbed by the roots for its physiological functions, while the rest is lost by transpiration.

MILLER in 1938, estimated the water budget of a Kansas maize plant (*Zea mays*) as follows—

Water occurring as a constituent...	1872 g
Water used as a reagent ...	250 g
Water lost in transpiration ...	202,106 g
	204,228 g

Types of Transpiration

Transpiration mainly occurs through the stomata and cuticle and accordingly is called *stomatal transpiration* and *cuticular transpiration.*

1. Cuticular transpiration—Cuticle is a layer of wax-like covering on the epidermis of leaves and green stems. The cuticle is impervious to water, so the water lost through it is less. Upto 10% of the total transpiration may take place through it. With the increase in the thickness of cuticle, the loss of water vapour through it is reduced.

2. Stomatal transpiration—Stomata are minute pores in the epidermis. Their opening and closing is controlled by guard cells. Maximum loss of water vapour takes place through these pores. The loss of water vapours through stomata amounts to about 80-90% of the total loss. Stomata are mostly situated on leaves but in green stems also they may be found in epidermis.

In dorsiventral leaves the lower surface has a large number of stomata. Therefore, it transpires more vigorously than the upper surface. In isobilateral leaves stomata are uniformly distributed on both the surfaces. Thus in such leaves transpiration is more or less equal on the two surfaces.

3. Lenticular transpiration—In woody stems, some transpiration also takes place through the loose mass of cells of the lenticels.

Wilting

Sometimes it is noted that the amount of water that a plant loses is much greater than its own weight, especially during a warm day. The water which is lost during transpiration must be made good by the absorption of watr by the plant from the soil and by the rapid conduction of this water through the stem to the leaves. If this does not happen the leaves show *wilting.* This type of wilting can be observed in plants during the afternoon hours when the roots are not able to absorb an adequate amount of water from the soil in order to compensate for the rapid loss of water from the exposed parts. Towards the evening, the shoot recovers as the rate of transpiration decreases. If the soil does not contain enough water, the plant will show, what is known as *permanent wilting.*

Internal Structure of Leaf in Relation to Process of Transpiration

When a transverse section of a leaf is examined under a microscope it shows a loosely packed mass of spongy cells of the mesophyll between the upper

and the lower epidermis. In between these cells there are a number of large intercellular spaces. These intercellular spaces are in communication with the outside atmosphere through the stomata. The cells of the mesophylll become turgid and saturated with water because of the osmotic diffusion of water from the xylem of the leaf veins. From the moist walls of these cells, water evaporates into the intercellular spaces. From there water diffuses out into the atmosphere through the openings of stomata.

oplasts. Stomata are very numerous, ranging from a few hundred per square centimetre of leaf surface in some monocotyledonous plants to many thousands in some trees.

In dicotyledons, the inner walls of the guard cells surrounding the stoma are thicker than the oute walls. Inflow of water in guard cells causes bulging of the outer walls, drawing the inner walls apart and opening the pore. Decrease in turgor · of the guard cells causes the inner walls return to their original positions resulting in the closure of the pore.

Fig. 6.1 Diagram showing exchange of gases.
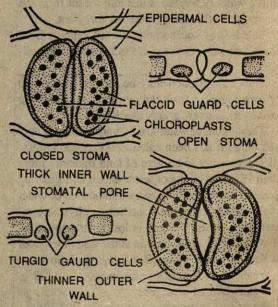
Fig. 6.2 Diagram to show opening and closing of stomata.

Structure of the Stomatal Apparatus

The stomata (singular, stoma) are the only apertures connecting the outer atmosphere with the intercellular spaces of the leaf. Thus they are the main pathways through which water vapours diffuse to the outer atmosphere during transpiration.

Each stoma is an elliptical pore found in the epidermis of leaves and green stems. The pore is bounded by two kidney-shaped epidermal cells called *guard cells*. The wall of guard cells towards the stoma is thickened while the outer wall is thin. The guard cells differ from ordinary epidermal cells not only in shape but also in having chlor-

In monocotyledons, stomata are dumbbell-shaped with thick intervening walls. The flow of water increases the turgidity of the guard cells, the regions with thin walls bulge drawing the thick walls apart and opening the pore.

Mechanism of Stomatal Opening and Closing

It is a well known fact that distension of guard cells is responsible for opening stomata. But the mechanism by which water enters the guard cells was explained by FUJINO (1967). According to him changes in turgor pressure that open and close the stomata result from the reversible absorption and loss of K^+ ions.

The stomata open when the guard cells take up K^+ ions from the surrounding medium. This hap-

pens when leaf is exposed to light. The uptake of K⁺ ions by guard cells decreases the water potential in the guard cells. As a result water enters the guard cells to make them turgid and the stomata open.

Uptake of K^+ ions is balanced by one of the following—

i. Uptake of chloride (Cl^-) ions.

ii. Transport of H^+ ions released from malic acid.

iii. By the negative charges of organic acids when they lose H^+ ions.

The exchange of K^+ ions from the guard cells leads to osmotic loss of water from the guard cells and the closure of stomata.

A number of factors influence the closure of stomata. Some plants show rhythms of opening and closing of stomata irrespective of the atmospheric conditions.

Under severe drought stress or intense solar radiation abscisic acid is produced which causes the closure of stomata. This prevents excessive water loss.

Factors Affecting Transpiration

Transpiration is affected by several external and internal factors—

(A) External Factors

1. Light—This is the most important factor affecting the rate of transpiration. Transpiration is not only accelerated by the direct sunlight but also by the diffused sunlight. Light affects transpiration in two ways. Firstly, it increases the transpiration by raising the temperature of leaves. Secondly, there is close relationship between the opening of the stomata and presence of light. During night when there is no light, stomata remain close resulting in minimum transpiration.

2. Humidity of air—Low and high humidity of air directly affects the transpiration. When the humidity is low, air becomes drier and receives moisture very readily. On the other hand when humidity increases, air becomes moist or saturated, it receives less water vapours, thereby decreasing the rate of transpiration.

3. Air temperature—Temperature also affects the rate of transpiration but indirectly. An increase in temperature decreases the humidity and vice versa. Transpiration also increases or decreases along with rise or fall in temperature.

4. Wind—The prevalence of wind greatly affects transpiration. During high wind, rate of transpiration is greatly enhanced as it removes the water vapours transpired, thereby, not allowing the transpiring surface to become saturated.

5. Available soil water—The rate of transpiration also depends on the amount of water absorbed by the roots. If absorption lags behind, the rate of transpiration also diminishes. The factors affecting absorption of water by the roots also indirectly affect the rate of transpiration.

(B) Internal Factors

6. Root-shoot ratio—The rate of transpiration directly depends upon the efficiency of the absorbing system (roots) and the evaporating system (leaves). The rate of transpiration increases with an increase in root-shoot ratio.

7. Leaf area—There seems to be no relation between leaf area and water loss. In large plants, the transpiration rate may be more per plant though on unit area basis, the rate of transpiration is more in the smaller plants than the larger ones. Further, decreasing the leaf surface by prunning often increases the rate of transpiration.

8. Leaf structure—Plants growing in dry conditions show several structural modifications in leaves to reduce transpiration. In such plants, the leaves are reduced and have thick cuticle, sunken stomata and presence of epidermal hairs. In certain plants, the leaves are modified into spines. In some other plants, sponge parenchyma is reduced and is replaced by palisade tissue in the leaves.

Significance of Transpiration

1. Transpiration helps in keeping the temperature of the plant low even when the plant is exposed to bright sunlight.

2. It helps in the distribution of water throughout the plant.

3. Transpiration helps in the rapid translocation of minerals and water through the xylem, once they enter the plant through the root hairs.

4. According to some, transpiration develops a suction force which helps in the ascent of sap.

5. Transpiration secures the concentration of the cell sap and thus helps in osmosis.

Anti-transpirants

Anti-transpirants are the chemical substances

that are used to reduce the rate of transpiration. These substances are sprayed on crop plants during dry season to avoid wilting when the rate of transpiration is high.

Anti-transpirants are of two types—

1. Metabolic inhibitors—These are phenyl mercuric acetate (PMA) and abscisic acid (ABA). These help in reducing the stomatal opening.

2. Film forming substances—These include mainly silicon emulsions which form a film on the surface of leaves and thus reduce the transpiration.

Uses

There are several possibilities of usage of anti-transpirants in agriculture—

1. Field crops—Usage of anti-transpirants helps in growing high yield crops with high water requirements in areas which go dry soon for most of the year.

2. Fruit cracking—Banana, tomato, cherry crack due to rainfall during the later stages of their ripening. Anti-transpirants could greatly reduce water absorption of fruit and save them from cracking.

3. Ornamental horticulture—Usage of film forming anti-transpirants reduce transpiration in them and hence can withstand dessication and delayed irrigation.

4. Usage in lawns—Spraying of lawns by anti-transpirants could check excessive water loss when the lawn is not watered for several days.

5. The usage of anti-transpirants in cut flowers could enhance their table keeping quality and prolong their freshness.

QUESTIONS

1. Discuss the mechanism of stomatal movement and conditions influencing them.
2. Explain how the environmental conditions bring about opening and closing of stomata.
3. Define transpiration. Mention various factors that control transpiration.
4. What is the significance of transpiration to plants.
5. Small leaves of a given variety of plant commonly transpire faster per unit area than large leaves when exposed to the same environment. Give explanation.
6. How opening and closing of stomata is controlled in light and dark respectively?
7. What are anti-transpirants. Discuss their importance in agriculture.
8. Plants lose water by the processes of .... and ....
9. Loss of water through the epidermis of aerial parts of the plant is reduced by ....
10. Stomata are mainly located on ....
11. Write a note on transpiration.

CHAPTER 7

Photosynthesis literally means putting together. It is the only process on earth by which solar energy is trapped by green plants (autotrophic organisms) and converted into food. Green plants synthesize carbohydrates from simple substances like CO_2 and water in the presence of sunlight. Carbohydrates produced by photosynthesis constitute the basic raw material which directly or indirectly gives rise to all the organic components of virtually all living beings.

Thus photosynthesis may be defined *as the synthesis of carbohydrates by the green organs of a plant in the presence of sunlight from CO_2 and H_2O taken up from the air and soil respectively, oxygen being a byproduct.*

This process is unique to green plants and it is the final light energy trapping process on which all life ultimately depends. As solar energy is necessary, this process cannot occur at night due to the absence of light. It is one of the most massive chemical event going on the earth. It has been estimated that plants take up 7×10^{11} tons of CO_2 to produce roughly 5×10^{11} tons of solid plant material, 90% of it in the oceans.

Magnitude of Photosynthesis

Atmosphere contains only about 0.03 per-cent carbon dioxide by volume. This small percentage represents 2200 billion tons of CO_2 present in the atmosphere. This much amount is sufficient for photosynthesis for a few hundred years even if no further amount of CO_2 is added. In addition to it, the oceans contain over 50 times the amount of atmospheric CO_2 in the form of dissolved gas or carbonates. From these two sources about 70 billion tonnes of carbon is fixed by the green plants annually.

Significance of Photosynthesis

Two major products are produced as a result of photosynthesis. These are oxygen and sugar. Oxygen liberated balances the atmospheric oxygen which is continuously consumed by the plants and animals during respiration.

Sugar produced during photosynthesis is used by plants to synthesize organic compounds, like carbohydrates, organic acids, proteins, fats, hormones, vitamins, alkaloids, etc.

Thus the solar energy trapped by green plants meets the food requirements of all other living beings. In addition, people use plants for fodder, firewood, timber, fibres and other purposes. Fossil fuels such as coal, petroleum and natural gas are also products of photosynthetic organisms which lived millions of years ago.

Development of the Knowledge of Photosynthesis

It is interesting to study how the concept of photosynthesis evolved from the time of ARISTOTLE and THEOPHRASTUS.

320 B.C. ARISTOTLE AND THEOPHRASTUS : These great philosophers thought plants absorb all inorganic and organic material directly from the soil.

1648 VAN HELMONT : He grew a small willow twig, weighing 5 pounds, in a barrel containing pre-weighed, oven-dried soil. He watered it for five years with rain-water. The twig grew into a young tree. He removed and weighed the tree. He found that it had gained 164 pounds and three ounces. He then re-dried the soil of barrel and weighed. It had only lost 2 ounces of the original weight. He, therefore, reached the conclusion that ALL VEGETATION IS NOTHING BUT WATER.

1727	STEPHEN HALES understood the importance of air and light in the nourishment of plants.
1772	JOSEPH PRIESTLY put a burning candle in a closed glass-container. He found that the air inside the jar had changed and would not allow another candle to burn or a mouse to live in it. Then he placed a twig of mint in an inverted glass jar in a vessel of water and after few days later found that "the air would neither extinguish a candle nor was it all inconvenient for the mouse which was put into it. He concluded that VEGETATION PURIFIES THE AIR WHICH HAD BEN IMPURED BY BURNING OF CANDLE.
1779	JAN INGEN-MOUSZ DISCOVERED the role of light and green parts of the plants in purifying noxious air.
1783	LAVOISIER identified the purifying gas produced by green plants in sunlight as oxygen and the noxious air produced by the burning of candle as carbon dioxide.
1782	SENEBIER demonstrated that with the increase of CO_2 concentrations the rate of oxygen evolution also increases.
1804	DE SAUSSURE showed the importance of water in this process.
1845	VON MAYER reported green plants convert solar energy into the chemical energy of organic matter:

$$CO_2 + H_2O \xrightarrow[\text{green plants}]{\text{Sunlight}} \text{organic matter} + O_2$$

1845	LIEBIG reported that the organic matter was derived from CO_2 and water was used in photosynthesis.
1862	SACHS discovered that the product of photosynthesis was starch.
1888	ENFELMANN plotted the action spectrum of photosynthesis.
1905	BLACKMANN enunciated the law of limiting factors.
1920	WARBURG used unicellular green alga *Chlorella* to study photosynthesis.
1932	EMERSON AND ARNOLD by flashing light experiment showed the existence of light and dark reactions.
1937	HILL demonstrated with the help of isolated chloroplasts in the presence of suitable electron acceptor, the photolysis of water.
1941	RUBEN AND KAMEN used O^{18} and reported that in photosynthesis oxygen comes from water.
1954	CALVIN traced the path of carbon in the dark phase of photosynthesis and gave the C_3 cycle (now named after him). He was awarded the Nobel Prize in 1960.
1954	ARNON, ALLEN AND WHATLEY used $^{14}CO_2$ to show fixation of CO_2 by isolated chloroplasts.
1965	HATCH AND SLACK discovered the C_4 pathway for CO_2 fixation in certain tropical grasses.
1985	HUBER, MICHEL AND DISSENHOFER crystallised photosynthetic reaction centre of bacterium, *Rhodobacter*. They analysed its structure by X-ray diffraction technique. The Nobel Prize in Chemistry for 1988 was awarded to them for this work.

CHLOROPLASTS

Chloroplasts are present in all the green parts of plants and leaves. There may be over half a million chloroplasts per square millimetre of leaf surface. These are mainly located in the mesophyll cells of leaves. The CO_2 reaches them through the stomata and water reaches them through veins.

Structure

In higher plants, the chloroplasts are discoid or lens-shaped. They measure 4-10 μ in diametre and 1-33 μ in thickness. Each chloroplast is bounded by a double membrane. Inside the membranes is found a ground substance, the *stroma* or *matrix*. Inside the stroma is found a system of chlorophyll bearing double-membraned sacs or laurellae. These are stacked one above the other to form *grana* (singular, granum). Individual sacs in each lamella are known as *thylakoids*.

Pigments

Three types of pigments *viz.* chlorophylls, carotenes and xanthrophylls are present in a chlor-
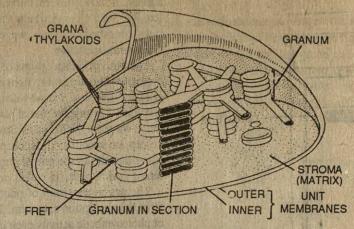
Fig. 7.1 Three dimensional structure of a chloroplast.

oplast. All the pigments are located in the thylakoid membranes. These pigments absorb light of a specific spectrum in the visible region. The pigments are fat soluble and located in the lipid part of the membrane. With the help of certain enzymes, they participate in the conversion of solar energy into ATP and ADPH. The enzymes of stroma utilise ATP and ADPH to produce carbohydrates.

(i) Chlorophylls— These are two predominant types of chlorophylls—*Chlorophyll a* and *chlorophyll l.*

Chemically chlorophyll molecule consists of two parts (a) A complex ring structure of alternating single and double bonds, the *porphyrin ring* and (b) a lengthy hydrocarbon tail attached to the porphyrin group called the *phytol.*

Chlorophyll *a* and *b* differ in the nature of groups attached to position X. Chlorophyll *a* has a methyl group (-CH$_3$) while chlorophyll *b* has an aldehyde group (-CHO)

(ii) Caroteroid pigments—Caroteroids are lipid compounds present universally in almost all the higher plants and several microorganisms. They are usually red, orange, yellow, brown and are associated with chlorophyll. They are of two types—the *carotenes* and *xanthophylls.* The carotenes are orange red and xanthophylls contain

THE SHADED PORTION OF THE PHEOPORPHYRIN RING HAS ALTERNATING SINGLE AND DOUBLE BONDS WHICH GIVE CHLOROPHYLL IT'S COLOR AND THE CAPACITY TO ABSORB LIGHT AND TRANSFER EXCITONS

THE HYDROPHOBIC PHYTOL SIDE CHAIN, WHICH ANCHORS AND ORIENTS THE CHLOROPHYLL MOLECULE IN THE THYLAKOID MEMBRANE
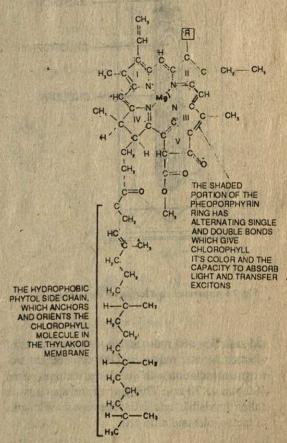
Fig. 7.2 Chemical Structure of Chlorophyl Molecule.

oxygen also. The light energy observed by the carotenoids is transferred to chlorophyll *a* to be utilised in photosynthesis.

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CAROTENE

XANTHOPY

CHLOROPHY

CHOLORY
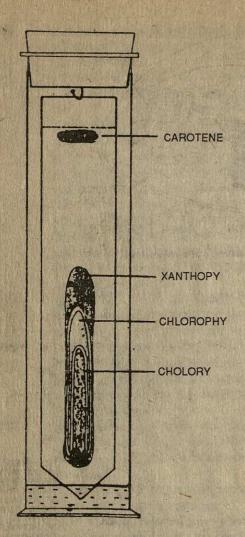
Fig. 7.6 Apparatus used for paper chromatography

red radiation and radio active waves are parts of electromagnetic radiation. One can see electromagnetic radiation with wavelengths ranging from 400 mm to 70 nm. This part of the spectrum is called the visible light. It lies between wavelengths of ultra-violet and infra-red.

Absorption and Action Spectrum

All the pigments of the chloroplast absorb light quanta or photons and transfer the absorbed energy to chlorophyll a. The amount of light absorbed at each wavelength can be depicted in the form of a graph. It shows differnt curves at different wavelengths. Such a curve which shows the amount of light absorbed at each wavelength is termed *absorption spectrum.*

The absorption spectrums of chlorophyll a and b clearly show that more light energy is absorbed at blue, violet and red wavelengths of the visible spectrum. The relative rate of photosynthesis at different wavelengths indicates close relationship with absorption spectrum of chlorophyll a and b. This curve that shows the rate of photosynthesis at different wavelengths is called *action spectrum.*

The action spectrum of photosynthesis differs from the absorption spectrum. There is quite a lot of photosynthetic activity even in parts of the spectrum where chlorophyll a absorbs little light. This infers that the light energy absorbed by other pigments (yellow and orange carotenoids and also other forms of chlorophyll) is transferred to chlorophyll a.

Mechanisms of Photosynthesis

Before 1930 it was considered that one molecule each of CO_2 and H_2O form a molecule of formaldehyde, of which 6 molecules on polymerisation form one molecule of sugar.

$$CO_2 + H_2O \rightarrow HCHO + O_2 \text{ (formaldehyde)}$$
$$6CH_2O \text{ (or HCHO)} \rightarrow C_6H_{12}O_6 \text{ hexose sugar}$$

Formaldehyde is toxic and may kill the plants. Hence, this hythesis was not acceptable.
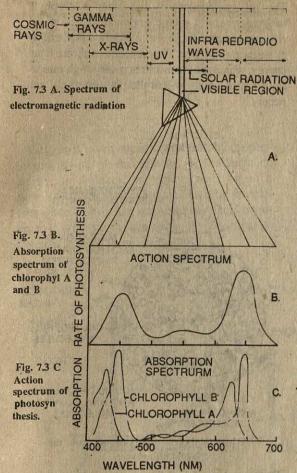
In 1931 VAN NEIL proved that bacteria use H_2S CO_2 to synthesize carbohydrates as follows—

$$6CO_2 + 12H_2S \rightarrow C_6H_{12}O_6 + 6H_2O + 12S$$

This led VAN NEIL to postulate that in green plants water is utilised in place of H_2S and O_2 is evolved in place of sulphur. RUBEN (1941) confirmed it by using *Chlorella.* He used water labelled with heavy oxygen ($^{18}O_2$) i.e. H_2 ^{18}O. The oxygen evolved contained ^{18}O, thereby proving VAN NEIL's hypothesis that oxygen evolved in photosynthesis comes from water. This led to the currently accepted general equation—

$$6CO_2 + 12H_2 {}^{18}O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6H_2O + 6 {}^{18}O_2$$

In 1937, HILL demonstrated that isolated chloroplasts evolved oxygen when they were illuminated in the presence of a suitable electron acceptor such as ferricyanide. The ferricyanide is reduced to ferrocyanide by photolysis of water. This is called HILL REACTION.

GAMMA RAYS
X-RAYS
UV
INFRA RED RADIO WAVES
SOLAR RADIATION
VISIBLE REGION

A.

Fig. 7.3 A. Spectrum of electromagnetic radiation

Fig. 7.3 B. Absorption spectrum of chlorophyl A and B

RATE OF PHOTOSYNTHESIS

ACTION SPECTRUM

B.

Fig. 7.3 C Action spectrum of photosyn thesis.

ABSORPTION

ABSORPTION SPECTRURM

CHLOROPHYLL B'

CHLOROPHYLL A

C.

400   ·500   600   700

WAVELENGTH (NM)

Experiment.1. Take some soft, green, non-mucilaginous leaves and grind them with acetone. Filter out the coloured solution. Observe it against transmitted light, that is, with the solution between you and the light source. It appears green. When the solution is seen with the light behind, that is, in reflected light, the solution appears red. The phenomenon is called *fluorescence.*

The photons absorbed by the molecule lose some of their energy and are given out as red photons.

Experiment 2. *To separate the chloroplast pigments by paper chromatography.*

Concentrate the extracted chlorophyll solution by evaporation. Apply a drop to one end, 2 cm from edge, of a strip of chromatographic paper and allow it to dry thoroughly. Take a mixture of petroleum ether and acetone in the ratio of 9:1 at a temperature of 40-60°C. Hang the strip in the

jar with its end dipping in the solvent. Close the jar tightly and keep it for an hour. The pigments separate into distinct green and yellow bands of chlorophyll and carotenoid respectively.

All photosynthetic plants have these pigments that absorb light between the red and blue regions

SUNLIGHT

TRANSMITTED LIGHT (GREEN)

EYE

EYE

REFLECTED LIGHT (RED FLUORESCENCE)

Fig. 7.4 Action spectrum of photosynthesis.

EXCITED STATE

HEAT

RED LIGHT (REMISSION) 10^{-9} SEC

GROUND STATE
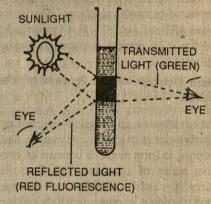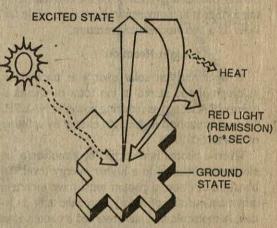
Fig. 7.5 Absorption of light

of the spectrum. Carotenoids found mainly in higher plants absorb primarily in the violet to blue regions of the spectrum. They not only absorb light energy and transfer it to chlorophyll but also protect the chlorophyll molecule from photo-oxidation.

Nature of Light

Light is a form of energy. It travels as a stream of tiny particles called photons. A photon contains a quantum of light. Light has different wavelengths having different colours. Light, cosmic rays, gamma rays, x-rays, ultraviolet radiation, infra-

Thus Hill reaction proves that—

(i) In photosynthesis oxygen is relased from water.

(ii) Electrons for the reductions of CO_2 are obtained from water, *i.e.* a reduced substance produced latter reduces CO_2.

According to ARNON in this process light energy is converted to chemical energy. This energy is stored in ATP and NADP, 2 H is formed as hydrogen donor. This process is known as photophosphorylation.

Modern Concept of the Process of Photosynthesis

Photosynthesis is an oxidation-reduction process in which water is oxidised to release O_2 and CO_2 is reduced to form sugar. It consists of two successive series of reactions. The first reaction requires light and is called *light or Hill Reaction*. Second reaction does not require light and is called *dark or Blacksman reaction*. Of the two reactions, the former is a photochemical reaction, while the latter is a thermochemical reaction.

1. Light Reaction

In light reaction solar energy is trapped by chlorophyll and stored in the form of chemical energy of ATP and as reducing power in NADPH. Oxygen is evolved in the light energy by splitting of water.

When a photon is absorbed by a molecule, an electron is boosted to a higher energy level. To boost an electron, a photon must have a certain minimum quantity of energy, hence the term *quantum*. A molecule that has absorbed a photon is in an energy-rich *excited state*. When the light source is turned off, the high energy-electrons return rapidly to their normal low-energy orbitals as the excited molecule reverts to its original stable condition, called the *ground state*.

Photochemical Reaction Systems

The light absorbing pigments are located in the thylakoid membranes. Situated in these membranes are clusters of chlorophyll and accessory pigments along with special types of chlorophyll molecules P_{680} and P_{700}. (The letter P stands for pigment and 680 and 700 for the wavelengths of light at which these molecules absorb light). P_{680} and P_{700} molecules form the *reaction centres* or *photocentres*.

The accessory pigments and other chlorophyll molecules harvest solar energy and pass it on the reaction centres. These are called *light harvesting* or *antenna molecules*. They function to absorb light energy, which they transmit at a very high rate to the reaction centre where the photochemical act occurs.
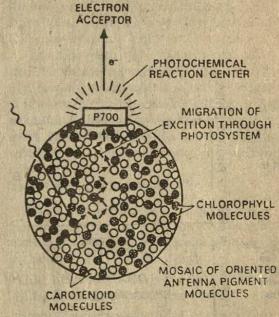
Fig. 7.7 Schematic diagram of a photosystem in the thylakoid membrane.

Photosystems I and II

The thylakoid membranes of chloroplasts have two kinds of photosystems, each with its own set of light harvesting chlorophyll and carotenoid molecules. Chlorophyll and accessory pigments help capture light over larger area and pass it on to the photocentres. Thus a photon absorbed anywhere in the harvesting zone of a P_{680} centre can pass its energy to the P_{680} molecule. The cluster of pigment molecules which transfer their energy to P_{680} absorb at or below the wavelength of 680 m. Together with P_{680} they form the *photosystem II* or *PS II*. Likewise, P_{700} forms *photosystem I* or *PS I* along with pigment molecules which absorb at or below 700 nm.

Operation of Photosystem II—This system is characterised by the photolysis of water releasing oxygen. In this act when PS II absorbs light, electrons are released and chlorophyll molecule is oxi-

dised. The electrons emitted by P_{680} (PSII) are ultimately trapped by P_{700} (PSI). The oxidised P_{680} regains its electron by the photolysis of water as follows—

$$4H_2O \rightarrow 4H^+ + 4OH^-$$
$$4OH^- \rightarrow 4(OH) + 4e^-$$
$$4OH \rightarrow 2H_2O + O_2$$
$$\overline{}$$
$$4H_2O \rightarrow 2O_2 + 4H^+ + 4e^-$$

Oxygen is given out as a byproduct by the photosynthesising plants. Protons (H^+) accumulate inside the thylakoid membrane resulting in a *proton gradient*. The energy released by the protons when they diffuse across the thylakoid membrane into the stroma against the H^+ concentration gradient is used to produce ATP.

Hydrogen attached to reduced $NADPH_2H$ is used for reduction of CO_2 in dark reaction. This it is also called the *reducing power of the cell*.

Photophosphorylation

Formation of ATP in the chloroplasts in the presence of light is called photophosphorylation. It takes place in two forms—

1. Cyclic photophosphorylation— Illumination of photosystem I causes electrons to cycle continuously out of the reaction centre of photosystem I and back into it. The cyclic electronic flow is accompanied by the photophosphorylation of ADP to yield ATP. This is termed *cyclic photophosphorylation*. Since this process involves only pigment system I, photolysis of water and consequent evolution of oxygen does not take place.
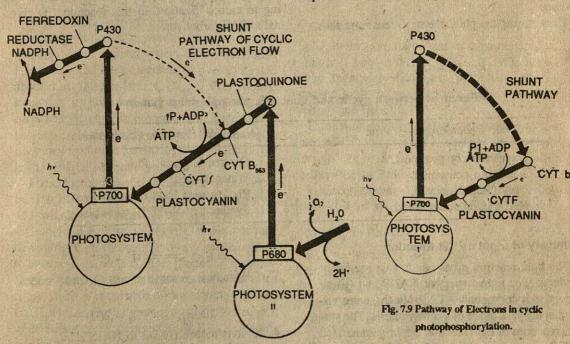
Fig. 7.8 The Cooperation of Photosystem I and II.

Fig. 7.9 Pathway of Electrons in cyclic photophosphorylation.

Operation of Photosystem I—When light quanta are absorbed by photosystem I (PS_{700}), energy rich electrons are emitted from the reaction centre. These flow down a chain of electron carriers to NADP along with the protons generated by the splitting of water. This results in the formation of $NADPH_2$.

Non-cyclic photophosphorylation—It occurs among green plants and involves both PS I and PS II. In this case, another electron transport chain starts with the release of electrons from PS II. In this chain high energy electrons released from PS II do not return to PS II but after passing through an electron transport chain enter PS I, which in turn donates it to reduce NADP to $NADPH_2$. The reduced NADP($NADPH_2$) is utilised for the
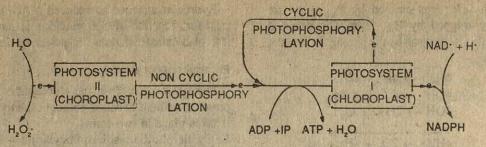
Fig. 7.10 Diagram showing inter relationship of photosystem I and II, photolysis of water and synthesis of ATP and NADPH$_2$

reduction of CO_2 in the dark reaction.

Since, in this process high energy electrons released from PS II do not return to PS II and ATP is formed, this is called *noncyclic photophosphorylation*.

Thus, during the photochemical reactions pho-

tolysis of water takes place, O_2 is released and ATP and NADPH$_2$ are synthesized. ATP and NADPH$_2$ molecules function as vehicles of transfer of energy of sunlight into dark reaction leaving to carbon fixation. In this reaction CO_2 is reduced to carbohydrate.

Differences between cyclic and noncyclic photophosphorylation

Cyclic Photophosphorylation	*Noncyclic Photophosphorylation*
1. Oxygen is not given off.	1. Oxygen is given off.
2. Water not consumed.	2. Water is used.
3. Only photosystem I is involved.	3. Photosystem I and II are involved.
4. NADPH$_2$ is not synthesized.	4. Synthesis of NADPH$_2$ takes place.

Summary of Light or Hill Reaction

The light reaction gives rise to two important products (i) a reducing agent NADP and (ii) an energy rich compound ATP. Both these are utilized in the dark phase of photosynthesis. The various reactions of light reaction can be summarized as follows—

1. Chlorophyll molecule (P) becomes excited on absorbing one quantum of light energy—

$$P + \text{light energy} \rightarrow \frac{\sim P}{\text{(activated pigment molecule)}}$$

2. The activated pigment molecule removes one electron from the (OH)$^+$ion derived from water molecule.

$$H_2O \rightleftharpoons H^+ + OH$$

3. (OH) radicals react to release O_2 and produce hydrogen:

$$2(OH) \rightarrow O_2 + 2(H)$$

4. H$^+$ ions reduce NADP to NADPH:—

$$NADP + H^+ + e^- \rightarrow NADPH$$

5. (OH) radicals also combine together to produce water:—

$$(H) + (OH) \rightarrow H_2O + \text{energy}$$

6. Above reaction is strongly energy releasing. This energy is utilized in the synthesis of ATP—

$$(H) + (OH) \rightarrow H_2O + \text{energy}$$

$$ADP + P_1 \xrightarrow{\text{energy}} ATP$$

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Photosynthetic Electron Transport

When the reaction centre of photosystem I is excited by light quanta received from the antenna molecules, there is a decrease in the light absorption of the reaction centre PS_{700}. The first electron carriers molecule in the chain from PS_{700} to $NADP^+$ is a *quinone*, designated P_{430}. The next electron carrier is *ferridoxin*. The iron atoms in quinore and ferridoxin transfer electrons via one-electron Fe(II)—Fe(III) valency changes.

Quinone and *ferredoxin* transfer electrons via one-electron Fe (II)—Fe (III) valence changes.

The third electron carrier is a flavoprotein called *ferredoxin-NADP oxidoreductase*. It transfers electrons from reduced ferredoxin to $NADP^+$, reducing the latter to NADPH :

$$2Fd^{2+} + 2H^+ \rightarrow Fd^{3+} + NADPH + H^+$$

There is a connecting chain of electron carriers, that leads electrons 'downhill' from the excited reaction centre of photosystem II to photosystem I. The oxidized reaction centre of photosystem II absorbs at 680 nm (hence, PS_{680}). Very little is known of its chemical nature. The first electron carrier in the chain is designated Z. The reduced form of Z passes electrons downhill to *plastoquinone* or PQ, which resembles ubiquinone of the mitochondrial respiratory chain.

The reduced form of plastoquinone donates electrons to a *b*—type chytochrome, called *cytochrome 563*, which in turn passes electrons to *cytochrome f*. Cytochrome *f* resembles cytochrome *c* of mitochondria. Cytochrome *f* in turn passes electrons to *plastocyanin*, a blue copper protein. The copper atom of this protein is the actual carrier of the electrons, since it is capable of undergoing Cu(I)—Cu(II) cycles. *Plastocyanin* is the immediate donor of electrons to the empty holes in PS_{700} of photosystem I.

The electron holes left in the reaction centre PS_{680} of photosystem II are refilled by electrons removed from H_2O by a little understood Mn^{2+} containing enzyme complex called H_2O-*dehydrogenase*.

2. BIOSYNTHETIC PHASE OR DARK REACTION OR CALVIN BENSON CYCLE

Carbon fixation occurs in the stroma by a series of enzyme-catalysed steps. Molecules of ATP and $NADPH_2$ produced in the thylaboids provide the stroma with the energy needed to fix CO_2 and to synthesize the carbohydrates.

Path of Carbon Fixation

The path of carbon fixation in dark reaction through intermediate compounds leaving to the formation of sugar and starch was worked out by CALVIN, BENSON and their coworkers in 1954. For this CALVIN was awarded NOBEL PRIZE in 1961.

Path of carbon was studied with the help of radioactive traces technique using *Chlorella*, a unicellular green alga and radioactive $^{14}CO_2$. With the help of radioactive carbon it became possible it was possible to trace the intermediate steps of dark fixation of $^{14}CO_2$.

The various steps in the dark reactions are as follows—

1. Carboxylation

CO_2 reduction starts with a 5-carbon sugar, *ribulose 1,5 biphosphate* (RuBP). It is a 5-carbon sugar (pentose) with two phosphate groups attached to it. It was formerly termed ribulose diphosphate (RuDP).

Three molecules of RuBP react with 3 molecules of CO_2 to produce a short-lived 6-carbon intermediate in the presence of an enzyme *RuBP carboxylase* or Rubisco.

Rubisco is a large protein molecule and comprises 16% of the chloroplast proteins.

2. Glycolytic Reversal

6 molecules of PGA form 1,3-diphosphoglyceric acid utilising 6 ATP molecules. These get converted to glyceraldehyde phosphate utilising 6 molecules of NADPH, supplied by the light reactions of photosynthesis.

3. Regeneration of RuBP

For the Calvin cycle to run continuously there must be sufficient amount of RuBP which accepts CO_2 and a regular supply of ATP and NADPH.

After a series of complex reactions, 5-molecules of phosphoglyceraldehyde and 3-molecules of ATP result in the regeneration of RuBP. Thus 6 turns of calvin cycle result in the production of one molecule of glucose. This used by the plant to form a variety of organic compounds required for its structure and function.

3 MOLCULES OF CO_2 (IC)

"RUBISCO"
(CARBOXYLATION)

3 MOLECULES OF
RIBULOSE BISPHOSPHATE (5C)

"RUBISCO"

3 ADP
3 ATP

6 MOLECULES OF
3 PHOSPHOGLYCERIC ACID (3C)

6 ATP
6 ADP

6 MOLECULES OF
13 DIPHOSPHOGLYCERIC (3C)

NADPH
6 NADP

6 P

GLYCOLYTIC REVERSAL

REGENERATION

5 MOLECULES OF
GLYCERALDEHYDE
PHOSPHATE (3C)

6 MOLECULES OF
GLYCERALDEHYDE
PHOSPHATE (3C)

1 MOLECULE OF
GLYCERALDE PHOSPHATE (3C)

GLUCOSE AND OTHER SUGARS

Fig. 7.11 Galvin cycle

Thus, for every 6 molecules of CO_2 and Ribulose 1, 5 biphosphate used, 12 molecules of 3-phosphoglyceraldehyde are produced. Out of these 12 molecules, only two are utilised for the formation of sugar, the other 10 molecules are converted into ribulose 1, 5 biphosphate which combines with CO_2.

Thus the Calvin cycle regenerates ADP and NADP required for the light reaction.

Summary of Photosynthesis

I. Light Reaction . . . (in granum)

$$24 H_2O \rightarrow 24OH^- + 24H^+$$
$$18ADP + 18Pi \rightarrow 18ATP$$
$$12NADP + 24H^+ \rightarrow 12NADP.2H$$
$$24OH^- - 24e^- \rightarrow 24OH$$
$$24OH \rightarrow 12H_2O + 6O_2$$

II. Chemical dark reaction . . . (in stroma)

$$6CO_2 + 18ATP + 12NADP.2H \rightarrow C_6H_{12}O_6 + 6H_2O + 18ADP + 18Pi + 12NADP$$

$$(I+II) \ 6CO_2 + 24H_2O \rightarrow \frac{Light}{Chloroplast} C_6H_{12}O_6 + 18H_2O + 6CO_2$$

Photorespiration

RuBP carboxylase which is the main enzyme of dark reaction also catalyses another reaction which interferes with the functioning of CALVIN cycle.

1. In the presence of high concentration of O_2, *RuBP carboxylase* acts as *oxygenase* and converts RuBP to 3-carbon compound PGA and a 2-carbon compound phosphoglycolate. The phosphoglycolate is converted immediately to glycolate.

2. Peroxisomes present in the cell metabolise the glycolate into glycine, and glycine into serum and

CO_2 witghout the produciton of ATP or NADPH. This process is called *photorespiration.*

It is estimated that as much as half of the photosynthetically fixed CO_2 may be lost by photorespiration. As no energy-rich compound is produced during this process, photorespiration acts to undo the work of photosynthesis.

With increase in temperature and O_2 concentration, the affinity of *RuBP carboxylase* for CO_2 decreases but it increases for oxygen. Thus with the rise in temperature , more and more fixed carbon is lost by photorespiration. In tropics over - coming the photorespiratory loss poses a challenge to growing plants.

C₄ Pathway or Hatch-stack Pathway

M.D. HATCH and C.R. SLACK (1966) of Australia, while working on sugarcane found four carbon compound (dicarboxolic acid) as the first stable product of photosynthesis. The *Hatch Slack Pathway,* as this alternative CO_2 fixation is called, has been found to occur in tropical and subtropical grasses and some dicotyledons. Some of the important plants are sugarcane, maize, sorghum etc.

The plants in which CO_2 fixation takes place by Calvin cycle only are called C_3 plants, because first product of CO_2 fixation is a 3-carbon phosphoglyceric acid. But in Hatch-Slack pathway, first product of CO_2 fixation is a 4-carbon compound, oxaloacetic acid. Hence such plants are called C_4 plants.

The anatomy of leaves of C_4 plants is different from leaves of C_3 plants. This type of anatomy is called *Kranz anatomy.* In the leaves of such plants, palisade tissue is absent. There is a bundle sheath around the vascular bundles.The chloroplasts in the bundle-sheath cells present are large and without or less developed grana, whereas in the mesophyll cells the chloroplasts are small but with well developed grana.

CO_2 taken from the atmosphere is accepted by a 3-carbon compound, phosphoenolpyruvic acid in the chloroplasts of mesophyll cells, leading to the formation of 4-C compound, *oxaloacetic acid.* It is converted to another 4-C compound, the malic acid. It is transported to the chloroplasts of bundle sheath cells. Here *malic acid* (C_4) is converted to pyruvic acid (C_3) with the release of CO_2. Thus

concentration of CO_2 increases in the bundle sheath cells. These cells contain enzymes of Calvin cycle. Because of high concentration of CO_2, RuBP carboxylase participates in Calvin cycle and not in photorespiration. Sugar formed in Calvin cycle is transported into the phloem.

Pyruvic acid generated in the bundle sheath cells
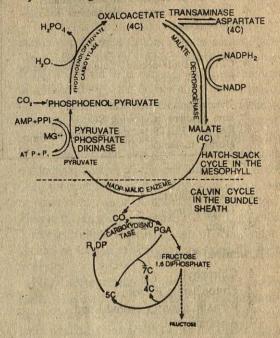
Fig. 7.12 Hatch-Slack Cycle.

re-enters mesophyll cells and regenerates phosphoenol pyruvic acid by consuming one ATP.

Since the converrsion results in the formation of AMP (not ADP), 2ATP are required to regenerate ATP from AMP. Thus C_4 pathway needs 12 additional ATP. The C_3 pathway requires 18ATP for the synthesis of one glucose molecule, whereas C_4 pathway requires 30ATP.

Thus C_4 plants are better photosynthesizers and there is no photorespiration in these plants.

Factors Affecting Photosynthesis

Like all other physiological processes, photosynthesis is also influenced by a number of factors. Factors influencing the process can be grouped in the following two heads :

A. External or Environmental Factors
1. Light

C_3 plants	C_4 plants
1. CO_2 acceptor is RuBP	1. CO_2 acceptor is phosphoenol pyruvic acid (PEP).
2. First stable product is phosphoglyceric acid.	2. First stable product is oxaloacetic acid.
3. Only one type of chloroplasts are present in the cells participating in photosynthesis.	3. Chloroplasts of bundle sheath are different from that of mesophyll cells.
4. Two pigment systems are present in each chloroplast.	4. Photosystem II is absent in the chloroplasts of bundle sheath. These are dependent on mesophyll chloroplasts for the supply of $NADPH + H^+$
5. Calvin cycle occurs in the chloroplasts of mesophyll cells.	5. Occurs in the chloroplasts of bundle sheath cells as the enzymes for Calvin cycle are absent in the chloroplasts of mesophyll cells.
6. Photorespiration occurs.	6. Absent.
7. Less efficient in utilising CO_2.	7. Much more efficient.
8. Requires 18ATP for the synthesis of one glucose molecule.	8. Requires 30ATP for the synthesis of one glucose molecule.

2. Carbon dioxide
3. Temperature
4. Water

B. Internal Factors

1. Chlrophyll
2. Protoplasmic Factor
3. Accumulation of Stored Food
4. Anatomy of Leaf

(A) External Factors

1. Light—It is an essential factor as it supplies the energy necessary for photosynthesis. Photosynthesis does not take place in darkness, regardless of the other environmental conditons. Both quality and intensity of light affect photosynthesis.

(i) **Quality of light**—While light consists of seven colours each having a different wavelength. The wavelengths of various colour rays affect the rate of photosynthesis variedly. HOOVER (1937) reported that the highest rate of photosynthesis takes place in the red rays and then comes the blue rays. Lowest rate was found in the green region. It is because of the fact that different rays of light are not absorbed equally by the chlorophyll.

Thus, when light passes through a forest canopy, there is preferential absorption of blue and red regions of visible light by the foliage. As a result the rate of photosynthesis decreases considerably in plants growing under the canopy.

(ii) *Light Intensity*—Intensity of light affects the rate of photosynthesis. In most of the plants photosynthesis is maximum in bright diffused sunlight. It decreases in strong light and again slows down in the light of very low intensity. If the supply of CO_2 is maintained constant, the rate of photosynthesis increases with the intensity of light till the maximum is reached. At this stage plant becomes *light saturated.*After this the rate of photosynthesis is controlled by carbon dioxide.

(iii) **Duration of light**—Duration of daily light period has a significant effect on the total photosynthetic yield of a plant. A plant will accomplish more photosynthesis when exposed to long periods of light. It has also been found that uninterrupted and continuous photosynthesis for relatively long periods of time may be sustained without any visible damage to the plant.

2. Carbondioxide—The chief source of CO_2 in land plants is the atmosphere, which contains only 0.3% of the gas. Under normal conditions of temperature and light, carbon dioxide acts as a limiting factor in photosynthesis. An increase in concentration of CO_2 increases the photosynthesis. The increase in CO_2 to about 1% is generally advantageous to most of the plants. Higher concentration of the gas has an inhibitory effect on photosynthesis.

3. Temperature—Like all other physiological processes, photosynthesis also needs a suitable temperature. In the presence of plenty of light and carbon dioxide, photosynthesis increases with the

rise of temperature till it becomes maximum. After that there is a decrease or fall in the rate of the process. The optimum temperature at which the photosynthesis is maximum is 25-30°C, though in certain plants like *Opuntia*, photosynthesis takes place at as high as 55°C. This is known as the maximum temperature. The temperature at which the process just starts is the minimum temperature.

For lichens it is as low as—20°C and for certain conifers it is—35°C.

4. **Water**—Being one of the raw materials, water is also necessary for the photosynthetic process. An increase in the water content of the leaf results in the corresponding increase in the rate of photosynthesis. Thus, the limiting effect of water is not direct but indirect. It is mainly due to the fact that it helps in maintaining the turgidity of the assimilatory cells and the proper hydration of their protoplasm.

B. Internal Factors

5. **Chlorophyll content of leaves**—Though the presence of chlorophyll is essential for photosynthesis but the rate of photosynthesis is not proportional to the quantity of chlorophyll present. It is because of the fact that chlorophyll merely acts as a biocatalyst and hence a small quantity is quite enough to maintain the large bulk of the reacting substances.

6. **Protoplasmic factor**—The plants which are transferred from dark to light do not start photosynthesis immediately. Same is the case with very long leaves. It is due to some internal factors present in the protoplasm, the exact nature of which is not known.

7. **Accumulation of byproducts**—The progress of photosynthesis in the assmilatory cells is maintained as long as the concentration of the products formed is removed. The final product in the photosynthetic reaction is sugar and its accumulation in the cells slow down the process of photosynthesis.

8. **Internal structure of leaf**—Leaf anatomy also plays a significant part in influencing the rate of photosynthesis. The thickness of the cuticle and epidermis of the leaf, the size and distribution of intercellular spaces and the distribution of the stomata and the development of chlorenchyma and other tissues also affect the rate of photosynthesis.

Blackman's Law of Limiting Factors

The Blackman's law of limiting factors states that when a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the 'slowest factor'. The slowest factor is that factor which is present in the lowest or minimum concentration in relation to others.

The law of limiting factor can be explained by taking two external factors such as carbon dioxide and light. Suppose, with a plant photosynthesizing at a fixed light intensity sufficient enough to utilize 10 mg. of CO_2 per hour, only 1 mg of CO_2 is entering the plant. In this case the rate of photosynthesis is conditioned by the CO_2 concentration. On increasing the CO_2 concentration, the photosynthetic rate also goes on increasing upto a concentration of 10 mg per hour. Now, if the CO_2 concentration is still further increased, no increase in the rate of photosynthesis will be noted. Thus in this case light becomes the limiting factor. Under such circumstances, the rate of photosynthesis can be increased only by increasing the light intensity.

Fig. 7.13 represents the whole concept graphically. This evidently shows that the photosynthetic rate responds to one factor alone at a time and there would be a sharp break in the curve and a plateau formed exactly at the point where another factor becomes limiting. If any one of the other factors which is kept constant (say, light) is increased, the photosynthetic rate increases again reaching an optimum where again another factor becomes limiting. The curve resulting from a lim-
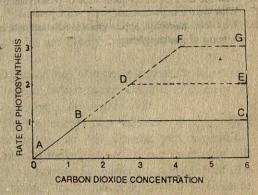
Fig. 7.13 Diagram to illustrate Blackman's principle of limiting factors.

iting factor is not an abrupt transition to the plateau state as proposed by BLACKMAN but a gradual transitional movement to a position approximately parallel to the abscissa.

QUESTIONS

1. With the help of suitable diagram describe structure of chloroplast.
2. What are thylakoids?
3. What are stroma and grana? Discuss their role in photosynthesis.
4. What is the difference between light and dark reactions?
5. What is a quantasome and a photon?
6. What is photophosphorylation?
7. During photosynthesis oxygen is evolved as a result of breakdown of CO_2 or H_2O ? Explain.
8. Give differences between C_3 and C_4 plants.
9. How does cyclic and noncyclic photophosphorylation differ ?
10. Draw a labelled diagram of a cross-section of chloroplast.
11. C_4 plants are more efficient in photosynthesis than C_3 plants. Explain.
12. Explain the role of photosystem I and II.
13. Explain the mechanism of CO_2 fixation and reduction in C_3 plants.
14. What is photolysis of water ?
15. Which wavelengths are more useful for photosynthetic plants ?
16. What are photosynthetic pigments ?
17. List the factors affecting photosynthesis.
18. Discuss the principle of Blackman pertaining to limiting factors.
19. List the products of light reactions.
20. Fill in the blanks by suitable words—
    (i) A cell that lacks chloroplast does not ....
    (ii) Photosynthesis takes place in the presence of ....
    (iii) .... is essential to trap radiant energy of the sun.
    (iv) Energy is transferred from the light reaction to the dark reaction by ....
    (v) Photorespiration takes place in .... plants.
21. Distinguish between :
    (a) Respiration and photorespiration.
    (b) Absorption spectrum and action spectrum.
    (c) Cyclic and noncyclic photophosphorylation.
22. Calvin cycle consists of three phases. What are they ? Explain the significance of each of them.
23. What is the advantage of having more than one pigment molecule in a photocentre?
24. Why are plants that consume more than the usual 18 ATP to produce 1 molecule of glucose favoured in tropical regions.
25. Explain why photosynthesis is considered the most important process in the biosphere ?
26. Describe the light independent steps of photosynthesis. How are they linked to the dark reactions?
27. What are the steps common in C_3 and C_4 plants?
28. Why does chlorophyll appear green in reflected light and red in transmitted light? Explain the significance of these phenomena in terms of photosynthesis.

CHAPTER 8

Osmo-regulation in Plants : Water Potential

Water is indispensable for all living organisms. It is the chief constituent of protoplasm. 66-90% of the body weight of all living organisms consists of water. Water acts as a reactant (as in photosynthesis) or as an end product (as in respiration) in several biological processes.

Water is an important solvent for nutrients and metabolic products of living beings. It also serves as a medium for the transport of inorganic salts and food materials from one part to another in the plant body.

A typical plant cell is surrounded by a cell wall made up of cellulose. The cell wall is permeable to water and the solutes dissolved in it. Internal to the cell wall is plasma membrane. It is semipermeable and allows only certian molecules to pass through it. In the centre of a mature plant cell is a large vacuole filled with cell sap.

Water enters the plant body from the soil through the root system. Before taking up the intake of water by the plants, it is necessary to understand *imbibition, diffusion, osmosis* and *osmotic pressure.*

IMBIBITION

The absorption of water by hydrophilic surfaces is called *imbibition.* Materials capable of imbibition such as proteins and cellulose in living beings cause seeds to swell when immersed in water. Sticking of doors and the desk drawers in the rainy season are the common examples of imbibition. This is caused by an increase in size caused by the imbibition of moisture by the cells of dry wood.

The amount of water imbibed by a substance is determined by the degree of cohesion of the molecules of the imbibing substance. The tenacity with which water molecules are held on an imbibing surface is a function of their water potential and the nature of surfaces. The closer the molecules are to the surface more firmly they will be held. The tenacity with which they are held may be expressed in terms of chemical potential or water potential. The process of imbibition has three important aspects—

1. **Change in volume**—Due to imbibition volume of the system increases. Total volume of the water imbibed plus the imbibing material is less after imbibition.

2. **Production of heat**—As the water molecules are adsorbed on the surface of the imbibant, they lose some of their kinetic energy which appears as heat.

3. **Pressure**—In a confined imbibing system great pressure is developed due to swelling.

DIFFUSION

Diffusion may be defined as the *movement of molecules or atoms of a substance from the place of higher concentration to the region of lower concentration.*

The exchange of gases like CO_2 and O_2 between the aerial organs of the plant and the atmosphere and also the movement of molecules of liquids, gases or solutes from the region of higher concentration to low concentration until the molecules are evenly distributed, takes place by diffusion.

Diffusion may also be defined as the movement of molecules from the region of their free energy to a region of lower free energy.

The free energy of a substance depends upon three factors, *viz.* temperature, pressure and the number of molecules present per unit volume. It is also known as *chemical potential* of the substance. Thus the rate of diffusion of a substance is dependent upon its free energy or chemical potential.

OSMOSIS

There are certain membranes which allow a solvent (water, for example) to pass through them freely but do not allow the passage of a solute. Such membranes are said to be semipermeable or differentially permeable, e.g. parchment paper, urinary bladder, egg membrane, etc.

When two solutions of unequal concentration are separated by a semi-permeable membrane, it allows free movement of water but prevents the diffusion of the solute. This results in setting up a condition called osmosis. Thus osmosis may be defined *as the passage of water molecules from a solution of its higher concentration to a solution of its lower concentration through a semi-permeable membrane without permitting the diffusion of the solute.*
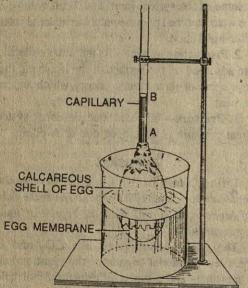
Fig. 8.1 Experiment to demonstrate the process of osmosis by means of a thistle funnel.

Significance of Osmoiss

1. It helps in the absorption of minerals and water by the plants.
2. It develops turgidity and turgos pressure in the plant cells.
3. Movement of water from one cell to another is due to osmosis.
4. Opening and closing of stomata is regulated by the osmotic entry and exit of water in the guard cells.
5. Resistance of plants to drought and frost is brought about by osmosis.

Experiment to demonstrate the process of osmosis by thistle funnel—Take a thistle funnel and tie its mouth with a piece of parchment paper or with a piece of sheep's bladder. This acts as a *semi-permeable membrane.* It allows the rapid passage of water molecules but obstructs the passage of larger molecules. Now fill the interior of the tube with a concentrated solution of sugar in water and place the whole apparatus in a beaker containing distilled water and mark the level of sugar solution in the thistle funnel.

After a few hours a rise in the level of water in the thistle funnel tube will be noticed. It is because of the fact that water from the beaker enters into the sugar solution in the funnel through the semi-permeable membrane. This process of diffusion of water through the semi-permeable membrane from a solution of lower concentration towards the solution of higher concentration is called *osmosis.* Due to the process of osmosis the solvent or water from the weaker solution passes on the side of the stronger solution and goes on accumulating there. The process of osmosis continues till the solution in the thistle funnel tube develops hydrostatic pessure which is sufficient enough to stop the further flow of the liquid. When water in the beaker is replaced by a stronger salt solution, the solvent (water) molecules diffuse from inside the funnel into the outer solution.
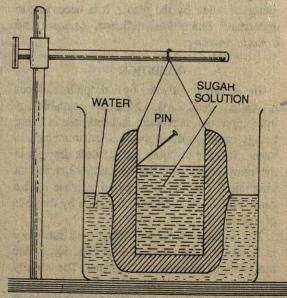
Fig. 8.2 Experiment to demonstrate the process of osmosis by means of a potato osmoscope.
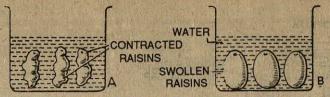
Fig. 8.3 Experiment to demonstrate osmosis in raisins: A—beginning of experiment, B—After sometime.

Experiment to demonstrate osmosis by means of potato osmoscope. Take a large sized potato. Remove its skin and cut its base to make it flat. Make a hollow cavity in the centre with the help of scalpel leaving a thin wall at the base. Fill this cavity with strong salt or sugar solution. Mark the initial level of the solution with the help of a pin. Hang this tuber within a beaker filled with coloured water. After a few hours the solution within the cavity is found to be at a higher level.

Endosmosis and Exosmosis

When a cell is placed in a solution of higher concentration than that inside its vacuole (hypertonic), water diffuses out of the cell. This flow of water is called exosmosis. Because of exosmosis cell becomes flascid. Reversely, if a cell is placed in a solution of lower concentration of solute, water enters into the cell. This phenomenon is known as *endosmosis*. Because of endosmosis cell becomes turgid.

Put some raisins in a dish full of water. Observe after few hours. These have swollen due to osmosis of water. In raisins, there is a stronger solution of sugar and the outer membrane of raisins serves as a semi-permeable membrane. Thus water enters into the raisins and makes them turgid. This shows endosmosis.

Now keep these swollen raisins in a strong sugar solution. After few hours they become flaccid. The water has diffused out from a solution of low concentration in the raisins into the outer solution of higher concentration. This is because of exosmosis.

PLASMOLYSIS

When a plant cell, say a thin section of a green leaf, coloured petal or a *Spirogyra* filament, is placed in a solution of higher osmotic concentration (hypertonic solution), exosmosis occurs. Because of exosmosis, water begins to move out of the cell. It results in the shrinkage of the protoplasm. This shrinkage of protoplasm is known as *plasmolysis*.

If a plasmolysed cell is again placed in a *hypotonic solution* (a solution of less concentration then the cell sap), water from outside enters the protoplasm. Because of the entry of water, protoplasm again comes back to its original position. This is called *deplasmolysis*.

Significance of plasmolysis—Plasmolysis is a vital phenomenon as it explains the process of osmosis. It also proves the permeability of the cell wall and semipermeability of the protoplasm. Secondly, this is helpful in dedtermination whether a cell is living or dead as the plasmolysis does not take place in a dead or nonliving cell. It is also used to determine the osmotic pressure of a cell.

Plasmolysis has got its useful applications as well. It is involved in the killing of weeds and in the preserving of meat and jellies.

Isotonic, Hypertonic and Hypotonic Solutions

If a solution in which a cell is placed has osmotic pressure equal to that of the cell sap, the outer solution is called *isotonic solution*. If the osmotic pressure of outer solution is more than that of the cell sap, the outer solution is known as *hypertonic solution*. In case the osmotic pressure of the outer solution is less than that of the cell sap, the outer solution is called *hypotonic solution*.

OSMOTIC PRESSURE

Osmotic pressure (OP) may be defined as the actual pressure which develops in solution when it is separated from pure water by means of a semipermeable membrane.

Osmotic pressure is measured as the minimum force required to prevent the osmotic entry of water into a system, when it is separated by a semipermeable membrane.
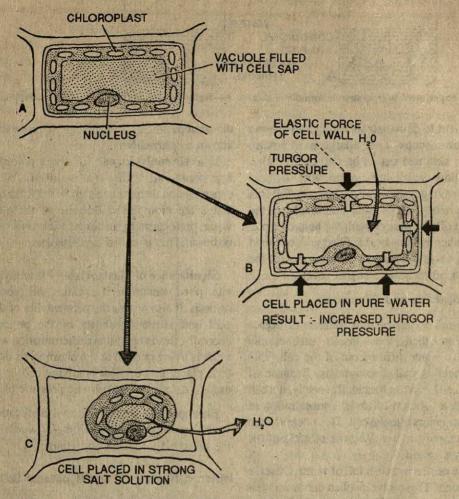
Fig. 8.4 Plasmolysis: (A) A cell in normal stage. (B) A cell placed in pure water and resulting in increased turgor pressure and (C) A cell placed in strong salt solution leading to plasmolysis.
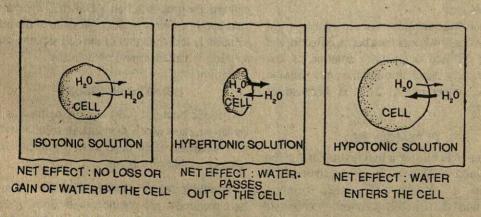
Fig. 8.5 Figures showing the effect of isotonic solution, hypertonic solution and hypotonic solution.

Osmotic Potential

When a solute is added to pure water (or solvent), it changes the free energy of water molecules.

It is observed that the free energy of water molecules (or solvent) changes on adding a solute to the solvent. This change in the free energy of water molecules is called the *osmotic potential* of the solution. Addition of the solute to the solvent lowers the free energy of the solvent (water) and increases the osmotic potential of the solution. On adding more water to the solution, the osmotic potential of the solution decreases.

Numerically, osmotic potential is equivalent to the osmotic pressure. Since it is not a real pressure, it is given a negative sign. The osmotic potential of pure water is taken as zero and it gets lowered when solute molecules are added to it.

When two solutions are separated from each other by a semipermeable membrane, the direction of the osmotic movement of water and the resultant osmotic pressure would depend upon the temperature, pressure and the solute molecules on the two sides.

The increase in temperature or pressure increases the free energy, while the increasing concentration of the solutes lowers it. In all these instances, water moves from a region of higher free energy to that of lower free energy.

Turgor Pressure

When a plant cell is placed in water, it enters the cell by osmosis. Such an entry of water results in a hydrostatic pressure called the *turgor pressure* (TP) which presses on the cell wall. Because of the elastic nature of the cell wall, it exerts an equal pressure but in the opposite direction to counter the turgor pressure. This pressure is called the wall *pressure* (WP). With the continued entry of water into the cell, the magnitude of WP keeps on increasing until the cell becomes fully turgid. When the cell becomes fully turgid wall pressure prevents further entry of water and WP becomes equal to TP—NP WP = TP

Significance of Turgidity

1. It is essential for plants to live and grow.
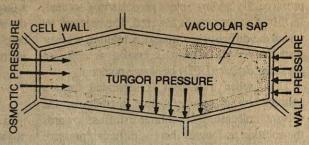
Fig. 8.6 A cell showing turgor pressure, Wall pressure and Osmotic pressure.

2. Turgor pressure aids in cell enlargement, consequently in stretching of stems and in keeping leaves erect and fully expanded.
3. Turgidity provides mechanical support to non-woody parts of the plant.
4. Loss of turgidity leads to wilting of leaves and dropping of shoots.
5. Opening and closing of stomata are regulated by the turgidity of the guard cells.
6. Leaf movements of many plants (like sensitive plant **Mimosa pudica**) are controlled by loss and gain of cell turgor.

Diffusion Pressure Deficit or Water Potential

All gases and solutes have a diffusion pressure. A pure solvent has the maximum diffusional
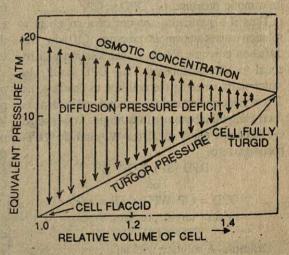
Fig. 8.7 Diagram illustrating the changes that occur when a plant cell takes up water. Note that when osmotic pressure and turgor pressure are equal in magnitude, the diffusion pressure deficit (DPD) is zero.

pressure. By adding solute particles in a solvent, its diffusion pressure is lowered. The pressure by which the diffusion pressure of a solution is lower than that of its solvent is known as *diffusion pressure deficit* (DPD) or water potential.

Thus, when a solvent is separated from a solution by a semipermeable membrane, the solvent molecules will continue to diffuse towards the solution as long as there is diffusion pressure deficit. In other words it can be said that the movement is due to diffusion pressure deficit (DPD) of the solution. In case of diffusion pressure deficit (DPD) the solution always tries to wipe off this deficit by sucking more of solvent molecules or in other words it can be said that DPD is the index of sucking power and is also known as *suction pressure* (SP). The DPD of the solution is initially equivalent to its OP (osmotic pressure). In a cell during osmosis, the increasing pressure forces the cytoplasm out against the cell wall. Since the cell wall is rather rigid it will exert an equal and opposite pressure called the *wall pressure* (WP). Due to WP, a decrease in DPD takes place. This can be expressed as follows—

DPD (SP) = OP—TP (WP)

Relationship between OP, TP (WP) and DPD (SP)

The DPD of a solution is initially equivalent to its osmotic pressure, *i.e.* DPD = OP.

Thus if a particular amount of a solute in a solution causes an osmotic pressure of 10 atm. the diffusion pressure deficit of that solution will be equal to 10 atmospheres. Thus DPD = OP. As water starts entering the cell due to osmosis, its TP starts increasing and the osmotic potential starts decreasing till it becomes fully turgid. At this stage OP becomes equal to TP (or WP) and the DPD becomes zero.

$$DPD (SP) = OP–TP$$
or
$$DPD = OP–WP \text{ (as TP = WP)}$$

In case turgor pressure is zero,
$$DPD = OP – 0 = OP$$

Example–A solution with an osmotic pressure of 10 atmospheres is enclosed by a membrane permeable to water. When this system is submerged in pure water, it starts moving into the internal solution through the membrane.

Soon an equilibrium is reached and at this stage,

a turgor pressure of 10 atmospheres is reached in the internal solution when the two systems reach equilibrium. Thus, at equilibrium, the DPD of the internal solution will be zero.

$$\text{At start OP} = 10 - 0$$
$$DPD = OP–TP$$
$$0 = 10–10$$

In a flaccid cell, TP = 0, the osmotic pressure of the cell sap is equal to its diffusion pressure deficit. When this cell is placed in pure water, there is a movement of water into the cell causing a turgor pressure to develop with an increase in cell volume, and there is a dilution and consequent decrease in the osmotic pressure of the cell sap. At the point where the osmotic pressure equals the turgor pressure and the diffusion pressure deficit equals zero, the cell is said to be fully turgid.

CONCEPT OF WATER POTENTIAL

The direction in which water flows from one part of the plant to another or even from one cell to another cell, depends on the *water potential* in the two regions. According to the principles of thermodynamics, every component of a system possesses free energy which is available for doing work. *The basic driving force in osmosis is difference in the free energy of water on the two sides of a semipermeable membrane.* The increase in temperature or pressure increases the free energy (energy available to do work), while the increasing concentration of the solutes lowers it. In each of the three instances water moves from a region of higher free energy to that of lower free energy.

The free energy of water is called the *water potential* and is given the value of zero at the prevailing temperature and atmospheric pressure. It is represented by the Greek letter ψ (Psi). ψ is measured in bars (a bar being close to one atmosphere of pressure). *Water moves from a region of high water potential to one of lower water potential.*

It is difficult to measure the absolute free energy or potential of water, but it is fairly easy to measure the difference in *water potential* between pure water and water in a solution such as the cell sap. This difference which was formerly termed the suction force or diffusion pressure deficit, is now generally termed the water potential. Its relationship to the terminology used in the past can be shown as:

Suction force = Osmotic pressure—Turgor pressure

Diffusion pressure deficit = Osmotic pressure—Turgor pressure

Water potential = Osmotic potential + Pressure potential

$$\psi w = \psi s + \psi p$$

Here ψw represents the potential of water in a cell, ψs the osmotic potential and ψp the pressure potential (hydrostatic pressure which develops in a cell due to the inward flow of water).
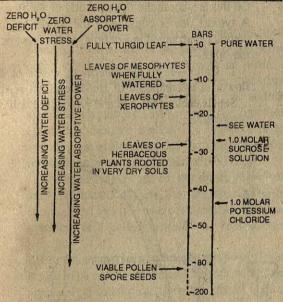
Fig. 8.8 The scale of water potential.

pressure. Pure water at atmospheric pressure has zero water potential ($\psi = 0$ bar). Water potential is lowered by adding solutes. Thus a 0.1 M (molar) solution containing any solute has a ψ or - 2.3 bars which is lower than the ψ of pure water. When such a solution is separated by a semipermeable membrane (such as plasma membrane), water will move from the region of pure water to that of the solution. This process is called *osmosis*. Soil water contains dissolved minerals and is generally a weaker solution than the solution of root hairs. Thus water moves into the roots from the soil.

In a system consisting of a solution separated from water by a semi-permeable membrane, movement of water can be prevented by applying pressure—*osmotic pressure* to the solution. The osmotic pressure... is balanced by the external pressure, which in the case of 0.1 M solution, this equal to + 2.3 bars.

When a plant cell is placed in a hypertonic solution, it loses water due to plasmolysis and the cell becomes flaccid. On the other hand, when a plant cell is placed in hypotonic solution, the cell absorbs water till it becomes turgid. Due to entry of water, protoplasm expands and exerts pressure on the elastic cell wall.This pressure is called *turgor pressure*. When the wall pressure equals turgor pressure then the entry of water into the cell stops. At this stage the water potential of the cell is equal to that of its environment. A dynamic equilibrium is reached in which there is no net movement, but equal exchange of water molecules can occur across the membrane.

Water potential is affected by two factors—These are the amount of solutes, and external

QUESTIONS

1. How does the diffusion involved in the water relations of a plant ?
2. Describe the importance of water in the life of a plant.
3. Describe osmosis.
4. Explain osmosis and osmotic pressure. How these are related to the life of a plant.
5. What is plasmolysis? How does it take in a cell ?
6. How is it possible for CO_2 to enter a leaf and O_2 to leave it at the same time ?
7. How is turgor maintained in plants.
8. What is the significance of turgidity to plants ?
9. Differentiate between osmotic pressure and turgor pressure.
10. Explain the relation between osmotic pressure, turgor pressure and suction pressure.
11. If a cell has an osmotic pressure of 8 atmosphere and its turgor pressure is 4 atmosphere, what would be its D.P.D.?
12. Name the process in which solvent molecules diffuse from the region of their higher concentrations to the region of their lower concentration through plasmalemma.
13. Define the following terms—
    (1) Osmotic pressure, (2) Osmotic potential, (3) Turgor pressure and (4) Wall pressure.
14. What would be the D.P.D. of (i) a fully turgid cell and (ii) a completely flaccid cell ?
15. Explain the terms isotonic, hypotonic, and hyperstonic.
16. Explain how the direction of flow of water between two cells is determined by the D.P.D.
17. What do you understand by water potential.
18. Describe the relationship between water potential, osmotic potential and pressure potential.

Structure and Functions of Flower

The flower and its parts are concerned with sexual reproduction in angiosperms. Morphologically flower is a modified shoot meant for the reproduction of the plant. Typically it is a condensed branch in which internodes have become condensed, bringing the nodes very close to one another, and the leaves are modified to form floral whorls that directly or indirectly participate in the process of reproduction.

Flowers differ greatly in size, shape, colour and arrangement of their parts yet most of them have a common structural plan.

PARTS OF A FLOWER

The flower is commonly borne on a short or long stalk called the *pedicel*. It has an upper swollen region known as *receptacle* or *thalamus*. On this are borne the floral whorls of the flower. A typical flower consists of the following four whorls *i.e.* arranged in a definite order, one above the other—

1. **Calyx**—It is the outermost whorl of the flower. It is composed of leaf-like green *sepals*.

Sepals enclose the bud and protect the delicate parts within.
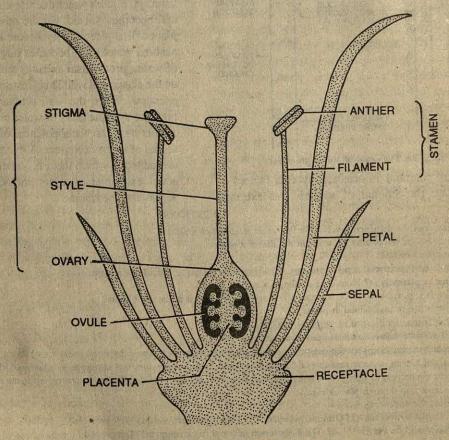
Fig. 9.1 Longitudinal section of a flower.

2. **Corolla**—It is the second whorl of the flower, and consists of a number of *petals*. In majority of the flowers, petals are brightly coloured and scented or of various shapes. They attract insects for pollination.

3. **Androecium**—This is the third whorl of flower and is the male reproductive organ consisting of *stamens*. Each stamen is made of three parts—*filament, anther* and *connective*.

The filament is a part of stamen that supports anther at its tip. The anther is four-chambered and bears granular mass of *pollen grains*. The connective joins the anther lobes.

4. **Gynoecium**—This is the last and the fourth whorl of flower and is the female reproductive organ of the flower. It is known as *pistil*. It occupies the central position on the receptacle and is composed of *ovary, style* and *stigma* and the component parts are called *carpels*. Ovary encloses egg-like bodies, the *ovules*. The stigma is sticky and receives pollens. Ovules form the seeds after fertilization and ovary becomes the fruit.

The sepals and petals are not directly involved in the reproduction. Thus, they are regarded as the *accessory whorls*, whereas androecium and gynecium are called *essential* or *reproductive whorls*.

Complete and Incomplete Flowers—A flower is said to be *complete* when all the four whorls are present, and *incomplete* when any one of them is absent.

Flowers that contain both stamens and pistil are termed *hermaphrodite* or *intersexual*. Flowers that bear organs of only one sex (staminate or pistillate) are called *unisexual*. Plants that bear flowers of both sexes are called *monoecious*. When male and female flowers are borne on different plants, these are called *dioecious, e.g. date palm, mullberry* and *coccinia*. In mango and cashew plants, neuter, male and intersexual flowers are found together.

Cohesion of Stamens—When the filaments of all the stamens are fused to form a single tubular structure but the anthers are free, they are said to be *monadelphous, e.g.* lady's finger, china rose and cotton flower.

When the filaments of the stamens are fused to form two bundles, it is called *diadelphous,* as in pea.

In *polyadelphous* condition the filament of the anthers are united to form a number of bundles and

the anthers remain free. Examples are castor. lemon, citrus, etc.

When the antehrs of the stamens are fused and their filaments remain free, *e.g.* sunflower, they are said to be syngenesious. This condition is a characteristic of the members of the families *Solanaceae* and *Compositae*.

When the stamens are free from each other *i.e.* anthers and filaments are not united or fused, they are said to be *polyandrous.*

Cohesion of carpels—When the gynoecium is made up of one carpel only, it is said to be *monocarpellary* or *multicarpellary* when made up of many carpels. When there are more than one carpels in a gynoecium, they may be free or *united*. If they are free it is called apocarpous *gynoecium* and when fused it is called *syncarpous gynoecium*. Syncarpous gynoecium may be bicarpellary, tricarpellary, tetracarpellary, pentacarpellary or multicarpellary.

The ovary may have one chamber (locule) or more than one chambers. Accordingly it may be called *unilocular ovary* or *bilocular, trilocular, tetralocular* or *multilocular* depending upon the number of locules in the ovary.

Placentation—The placenta is the cushion-like structure to which the ovules are attached inside the cavity of the ovary. On the basis of the distribution of the placenta, placentation is of the following types—
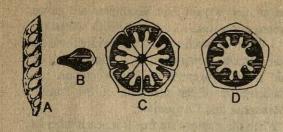
(i) **Marginal**—In this type of placentation, the ovary is simple, unilocular and the ovules are arranged along the margin of the unilocular ovary. The placenta develops along the ventral suture of the ovary.

Examples—Pea, gram, goldmohur, etc.

(ii) **Axile**—In axile placentation, the gynoecium is polycarpellary and the ovary multilocular. The number of loculi present corresponds to the number of carpels. The adjacent margins of the carpels project inwards, right upto the centre of the ovary where they meet and fuse with others to form a central column. This central or axile column thickens to form an *axile placenta* to which ovules are attached. The inturned margins of two adjoining carpels form the true septa.

Examples—*Ocimum, Althea,* Lemon, Orange, etc.

(iii) **Central**—In the free central placentation, the gynoecium is *polycarpellary* and *syncarpous*.
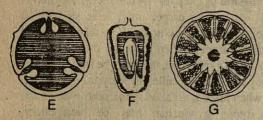
Fig. 9.2 A. Marginal in L.S.; B. in T.S.; C. Axile;
D. Central; E. Basal.; F. Parietal;
G. Superficial.

The ovary in early stages is multilocular, but soon the septa break down leaving it as a unilocular structure.

Examples—Pink (*Dianthus*), *Silene, Primula,* etc.

(iv) **Parietal**—In parietal placentation, the ovary is usually one-chambered but in some cases becomes bilocular due to the formation of false septum, *e.g. Brassica compestris* (sarson). The placentae bearing the ovules develop on the inner wall of the ovary at places where the margins of two adjoining carpels meet. The number of placentae corresponds to the number of fused carpels.

Examples—Poppy, mustard, *Cactus, Viola,* etc.

(v) **Basal**—In basal placentation ovary is *bicarpellary, syncarpous* and *unilocular.* The placenta which develops directly on the thalamus bears a single ovule at the base of the ovary.

Examples—Marigold, sunflower, etc.

(vi) **Superficial**—In superficial placentation the ovary is *multilocular, polycarpellary* and *syncarpous.* The ovules are borne over whole of the inner surface of the ovary.

Examples—*Nymphaea,* water lily, etc.

Depending upon the form of thalamus and the position of floral whorls with respect to the ovary,

the flowers are of the following three types—

(i) **Hypogynous**—The thalamus is convex-like and ovary occupies the highest position on it. The outer three whorls *viz.* sepals, petals and stamens are inserted one above the other but below the ovary. Since the ovary lies above all the other parts, it is described as *superior* and the rest of the floral whorls as *inferior.*

Examples—Buttercup, brinjal, china rose, mustard, etc.

HYPOGYNOUS PERIGYNOUS PERIGYNOUS EPIGYNOUS
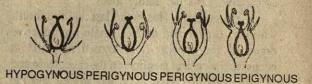
Fig. 9.3 Different types of insertion of floral leaves.

(ii) **Perigynous**—In some cases, the receptacle or the thalamus forms a shallow or deep cup-shaped structure around the ovary. The pistil is attached at the centre of the concave thalamus. The sepals, petals and stamens are attached at the margins of the thalamus. In such cases, where the sepals, petals and stamens arise at the margins of the thalamus, the flowers are said to be perigynous and ovary is superior. Different types of flowers show different degree of perigyny. The common examples of perigynous flowers are rose, pea, bean and *Prunus.*

(iii) **Epigynous**—In this case, the thalamus not only surrounds the ovary completely but also encloses it and fuses with the ovary wall. The sepals, petals and stamens arise from the top of the ovary. Such flowers are said to be *epigynous.* The ovary in these flowers is described as *inferior* and the other whorls are described as *superior.*

INFLORESCENCE

The arrangement of flowers on the floral axis is known as inflorescence. Depending upon the arrangement of flowers, inflorescence is classified as follows—

1. Recamose, 2. Cymose, 3. Special Types
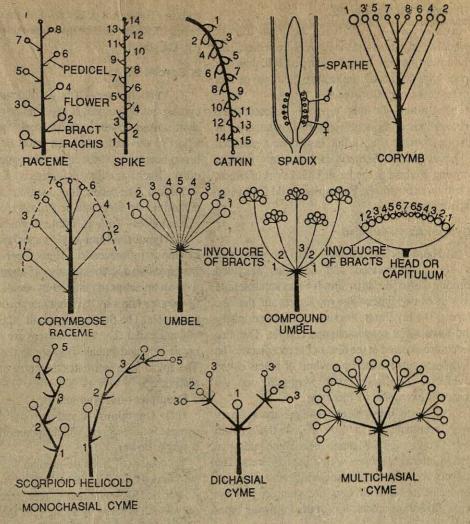
Fig. 9.4 Different types of inflorescence.

A. Main Axis Elongated

(a) **Raceme**—The main axis is elongated and bears flowers laterally. The flowers are stalked and arranged in acropetal successions, e.g. radish and mustard.

(b) **Spike**—Here also the main axis is elongated but the flowers are sessile and arranged in acropetal succession, e.g. *Amaranthus*.

(c) **Spikelet**—This is a very small spike with reduced axis, hence called *spikelet*. It bears one or a few small flowers. The spikelets arise in a racemose manner on the main axis, e.g. wheat, sugarcane, paddy, etc.

(d) **Catkin**—It is also a spike with a long and pendulous axis. It bears unisexual sessile flowers e.g. mulberry.

(e) **Spadix**—This is also a spike with a long, thick and fleshy axis. The floral axis is covered with one or more coloured spathe bracts. The spathes cover and protect the flowers. The male and female flowers are closely packed together. The female flowers are borne at the basal portion and above these are situated male flowers. Above them are sterile florets forming downward hairs. The spathe and the upper portion of the fleshy axis which is sterile, becomes coloured and serve to attract insects for pollination. The flower portion of the spathe becomes tubular enclosing the floral region. It affords protection to the flowers. The male and female flowers are separated by hair-like sterile flowrs, e.g. *Colocasia*, banana, maize, aroid, etc.

(B) Main Axix Shortened

(a) **Corymb**—In this case the main axis is comparatively short and the flowers are pedicellate. The lower flowers have longer pedicels than the upper ones so that all the flowers lie more or less at one level e.g. *Coriander.*

(b) **Umbel**—In this type of inflorescence, primary axis is shortened and the flowers arise in groups from the tip. All the flowers have pedicles of equal length. Sometimes bracts are present forming a whorl at the base. This whorl of bracts is known as *involucre*. **Examples**—wild *Coriander* and onion.

(C) Main Axis Flattened

(d) **Head or Capitulum**—Here the main axis is highly suppressed and becomes flattened forming a disc-like structure. It bears small sessile flowers of two types—the *ray florets* and the *disc florets*. The ray florets are situated at the periphery and have a flat tongue-shaped corolla. The disc florets are situated at the disc or the receptacle. The florets are surrounded by a whorl of bracts called involucre. Sunflower and Marigold are the common examples of this type.

2. Cymose inflorescence—Here the primary axis terminates in a flower but the growth continues through the lateral buds. These buds give rise to lateral branches which bear flowers. The flowers are arranged in *basipetal succession* i.e. the outer or basal flowers are younger and the upper flowers are older. It is of the following types :—

(a) **Monochasial Cyme**—The main axis ends in a flower and produces a single lateral branch and bears a flower. Other lateral branches are produced in the same pattern. It is of two types as follows:

(i) **Helicoid cyme**—Here the lateral branches bearing flowers are produced successively on the same side forming a sort of curve or helix, e.g. *Begonia* and *Solanum nigrum*.

(ii) **Scorpioid cyme**—In this case, the lateral branches bearing flowers at their tips develop alternately forming a zig-zag structure, *e.g. heliotrope*.

(b) **Bichasial cyme**—Here the main axis ends in a flower and produces two lateral branches which behave like the parent axis, *e.g.* jasmine.

(c) **Polychasial cyme**—Here also main axis ends in a flower but produces more than two lateral branches which also behave like the mother axis, *e.g.* Calotropis.

3. Special Types

(i) **Verticillaster**—It is a condensed form of cymose inflorescence. It is a cluster of sessile or short-stalked flowers in the leaf axil forming a false whorl at the node. At each node there are two bracts bearing a cluster of flowers opposite to each other. Each auxillary cluster is a condensed dichasium. The succeeding daughter axes of each dichasium develop into *scorpioid cymes*.

Examples—*Coleus*, mint, *Ocimum.*

(ii) **Hypanthodium**—It is a specialized form of racemose inflorescence. Here the receptacle is modified into a hollow, fleshy cup-shaped structure with an apical pore guarded by small scales. The flowers are borne by the inner margin of the hollow receptacle. The flowers are small, highly reduced and unisexual. The male flowers are borne at the upper side and female flowers at the basal side. The apical pore facilitates the entry of insects for pollination.

Examples—Banyan and fig.

(iii) **Cyathium**—Cyathium is a modified cymose inflorescence, which apparently looks like a single flower.

It consists of a single median female flower, surrounded by numerous male flowers. The female flower is pedicellate and is represented by pistil only which is borne on a long stalk the *gynophore*. The male flower is in the form of a stamen. Each stamen represents a male flower, is established by the fact that each is distinctly joined to a long pedicel and has a scaly bract at its base. All these flowers are enclosed in a cup-shaped *involucre* which is formed by the union of large number of bracts of the inflorescence. It is usually brightly coloured and possesses crescentic *extra flower nectaries.*

Examples—*Euphorbia and Poinsettia.*

Development of Pollen or Male Gametophyte

Anther

The anther consists of two lobes, the *anther lobes*, connected by a *connective*. Each anther lobe has two *pollen sacs* or *pollen chambers* placed longitudinally. There are longitudinal grooves or
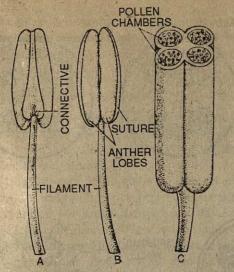
Fig. 9.5 Stamen, A-Dorsal view; B-Ventral view; C-Enlarged portion showing T.S. of anther.

of cells. The middle layers and the tapetum are usually crushed by the time actual meiosis occurs
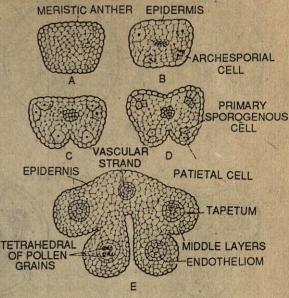
Fig. 9.6 Development of anther.

sutures along the ventral face of the anther demarcating the pollen chambers. Each pollen chamber represents a *microsporangium* and contains innumerable *microscpores* or *pollens*.

Microsporogenesis and Microspores

Microsporangium

During the development of the microsporangium, the anther appears to be a homogeneous mass of meristematic cells, oblong in cross-section and surrounding by epidermis. It then becomes four lobed and four rows of archesporial cells are differentiated. The archesporial cells are marked off from the surrounding cells by their more deeply stained cytoplasm and conspicuous nuclei. Each of the archesporial cells now cuts off a primary parietal cell on the inner side. The parietal cell now divides by periclinal and anticlinal walls giving rise to several layers of cells forming the wall of the anther. The sporogenous cell divides to give rise to a number of *microspore* or *pollen mother* cells.

The innermost layer of wall cells directly abutting on the sporogenous tissue forms the *tapetum* which is a nutritive tissue nourishing the developing microspores. The wall cells just below the epidermis form the *endothecium*, which later loses the cell-contents and forms the dry coat of the mature anther. Between the tapetum and the endothecium there are one to three *middle layers*

Fig. 9.7 Transverse section of anther showing various tissues.

in the sporogenous cells.

Microsporogenesis

During microsporogenesis the nucleus of each *microspore mother cell* undergoes meiosis or reduction division and ultimately gives rise to four *haploid nuclei*. These four nuclei are arranged tetrahedrally and are soon invested with cell walls. These are now called the *microspores* or *pollens*. These soon dry up and become powdery while the tapetum becomes absorbed. The anther now
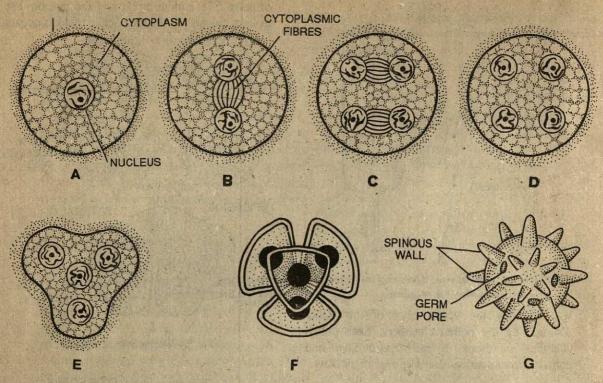
Fig. 9.8 Development of pollen grains from microspore mother cell.
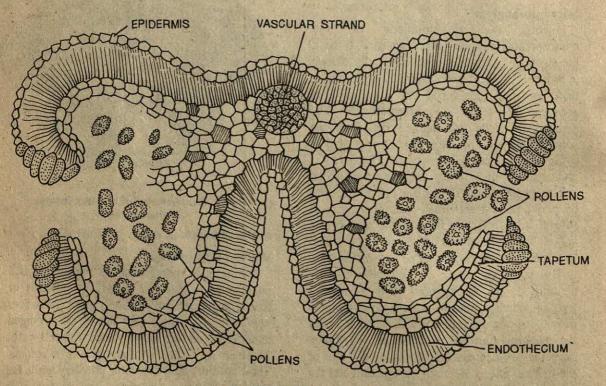
Fig. 9.9 T.S. of dehisced anther

becomes a dry structure, the partition walls between the sporangia are destroyed and the microspores are soon liberated by dehiscence of the anther.

Structure of the Pollen Grain

Pollen grains are the male reproductive structures that develop from the diploid mother cells in pollen sacs of the anthers. They are also known as *microspores*.

Typically, each pollen grain is a haploid and unicellular body with a single nucleus. It is usually round or oval, polyhedral in shape with 0.025 mm. to 0.125 mm. in diameter. There is a tiny mass of protoplast surrounded by a thick cell or spore wall. The spore wall is double-layered. The outer or *exine* is thick, cutinized and waxy. It is usually provided with spinous outgrowths. At certain places, exine remains unthickened or missing and these places are known as *germ pores*. The inner *intine* is thin, delicate and is made of cellulose.

Dissemination of Pollen Grains

The pollen grains are usually dry and powdery and disseminated singly. But in some flowers peculiar conditions are met with. In *Anona, Elodea, Typha,* etc. the four spores in a tetrad never separate but form *compound pollen grains*. In *Calotropis* and *orchids*, the pollens of each anther lobe form a characteristic mass called *pollinium*. Each pollinium is provided with a stalk called *caudicle* and a sticky based called *disc* or *corpusculum*.

Development of Male Gametophyte

While still in the anther lobe, pollen grains begin to germinate. The micronucleus moves towards the spore wall and divides mitotically. At this stage pollen grain or microspore contains two nuclei— a large *vegetative nucleus* and a small *germinative nucleus*. Both these nuclei lie freely in the cytoplasm of the pollen grain. Pollination usually takes place at this two-celled stage.

When the mature pollen grain reaches stigma, it absorbs moisture and swells. The exine ruptures at the germ pore. The contents surrounded by the intine stretch and extend out through the germ pore, forming a tubular outgrowth called the *pollen tube*. It grows down through the style and enters the micropyle of the ovule. The tube and the generative
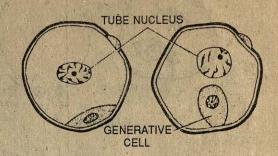
Fig. 9.10 Early stages of the development of the male gametophyte. A. The first division. B. Generative cell is detaching itself from the wall.

nuclei are carried by the pollen tube, the former lying at its tip. The generative nucleus divides to give two equal non-motile *male nuclei* or *gametes*. The tube nucleus now gets disorganised. Of the two male gametes, one fuses with the egg or ovum and the other with the secondary nucleus as soon as the pollen tube pierces and enters the embryo sac.

OVARY AND THE OVULE

Ovary is the most important part of the carpel as it contains the ovules which develop into seeds. There is a special tissue called *placenta* along the margin. The marginal line along which the carpel fuses is called the ventral *suture*, and the midrib as the dorsal suture. Ovules develop from this placental tissue and remain within the ovary.

Structure of the Ovule

The ovule represents the *megasporangium*. The body of the ovule is made up of two distinct parts, the *funicle* or *funiculus* and the body. The funicile is short, multicellular and attaches the main body of the ovule to the placenta. The point of attachment of the body of the ovule to the funicle is known as *hilum*.

The main body of the ovule is oval in shape. It is composed of thin-walled *parenchymatous* cells and is known as *nucellus*. It is surrounded by one or two cellular coats called *integuments*. The basal parts of the nucellus is somewhat swollen and is known as *chalaza*. There is a small opening at the apex of the integuments called *micropyle*. Embedded in the nucellus and towards the
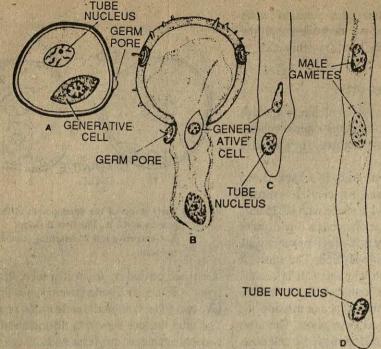
Fig. 9.11 Development of the male gametophyte. A. Binuleate stage. B. Infine coming out through a gempore a spollen tube C. Tip of a pollen tube. D. Pollen Tube showing two male gametes and tube nucleus.
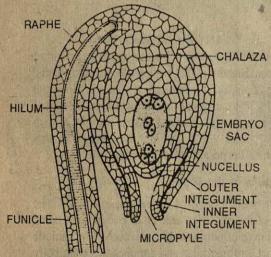
Fig. 9.12 Longitudinal section of the ovule showing various parts of fully formed ovule.

(ii) **Nucellus**—It forms the nourishing tissue for the developing embryo.

(iii) **Micropyle**—It is this aperture through which the pollen tube enters the embryo sac.

(iv) **Integuments**—Their function is to give protection to the inner tissues.

(v) **Embryo sac**—It contains the egg apparatus and develops inside the nucellus.

Various Forms of Ovules

Following four principal types of ovules are found in angiosperms —

1. **Orthotropous**—This is the most primitive type of ovule. In it the funicle is straight and ovule also lies straight in the ovary. The funicle, chalaza and micropyle lie in one vertical line.

Example—*Rumex,* walnut and *Polygonum.*

2. **Anatropous**—This is the most common type of ovule. In it the body of the ovule is inverted and micropyle lies close to the hilum. The funicle in curved at the apex and fuses with the integuments forming raphe. In it the micropyle and chalaza lie in one vertical line. **Examples :** Gram, pea, etc.

micropylar end, there is an oval sac called *embryo sac*. This is the most important part of the ovule.

Functions of Various Parts

(i) **Funicle**—It helps in the attachment of the ovule with the placenta.

ORTHOTROPUS ANATROPUS AMPHITROPUS CAMPYLOTROPUS

Fig. 9.13 Various forms of ovules.

3. **Amphitropous**—In this type ovule lies transversely at right angles over the stalk of the funicle. The micropyle and chalaza lie in one transverse line instead of vertical line. **Examples:** Citrus, lemon, etc.

4. **Campylotropous**—In it the body of the ovule becomes curved or bent, like a horse shoe so that the micropyle, funicle and chalaza come to lie at one pole and the funicle does not fuse with the integuments.

Examples—*Capparis,* mustard, etc.

Megasporogenesis and Development of Female Gametophyte

The *ovule* or the *megasporangium* develops as a small protuberance of the placental tissue. In the very young ovule a single hypodermal cell is differentiated as the *archesporium cell*. This cuts off some *parietal cells* and then becomes the *megaspore mother cell*. The megaspore mother cell now undergoes meiosis or reduction division and a linear row of four haploid *megaspore cells* is formed. Meanwhile two integuments develop from the base of the ovule. Of the linear tetrad of megaspores, usually the lower most one enlarges and becomes the functional megaspore while the three on top disintegrate.

PARIETAL A INTEGUMENT
CELL
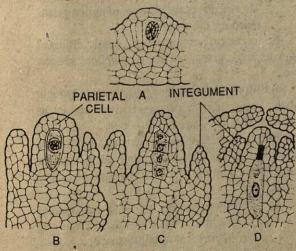
Fig. 9.14 Stages of ovule development and megasporogenesis.

FUNCTIONAL MEGASPORE

SYNERGIDS

EGG-CELL

FUSION NUCLEUS (SECONDARY NUCLEUS)

ANTIPODAL CELLS
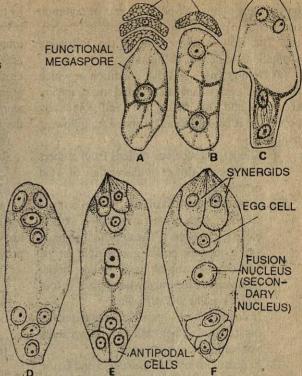
Fig. 9.15 Development of the female gemetophyte or embryo sac.

The *functional megaspore* now develops the *female gametophyte* or the *embryo sac*. The nucleus of the embryo sac divides into two, then four, and finally eight daughter nuclei, four of which are located at each pole. One nucleus from each pole moves to the centre of the embryo sac and fuses thrce forming the fusion or *secondary nucleus*. Three nuclei at the base form the *antipodal cells*. On the top, three cells form the egg apparatus which consists of two synergids and an *egg cell*.

POLLINATION

Upon maturity, the anther dehisces to liberate the pollen grains. For effecting fertilization, pollen must reach the right stigma which would support its germination and the subsequent growth of the pollen tube.

The transfer of the pollens from the anther to the stigma is called *pollination*. It is of two types—(1) Self pollination and (2) Cross pollination.

1. **Self Pollination**—It takes place in bisexual flowers where the anthers and stigma mature simultaneously. In such cases, stigma receives the pollens from the same flower or different flower

on the same plant. Self-pollination is of common occurrence in most of the grasses, cereals, tobacco, etc. The flowers show one of the following adaptations to secure pollination.

(a) **Homogamy**—It is that condition in which flowers are bisexual and anthers and stigma mature at one time to make the self-pollination possible. It is brought about by one of the following methods :—

(i) The stigma receives pollens from anthers of the same flower by the agency of wind or insects.

(ii) In some cases filaments of the anthers recoil in such a way as to bring anthers close to the stigma. The anthers then burst and scatter the pollen grains right on the surface of stigma and bring about pollination. This usually takes place in four o'clock plant and *Mirabilis*.

(iii) In some flowers stigma recoils and touches the matured anthers and thus brings about pollination, *e.g.* sunflower.

(iv) In some flowers like *Gardenia* and *Ixora*, the anthers lie at the mouth of narrow corolla tube and as the stigma pushes out through the tube, they shed their pollens on the stigma and bring about pollination.

(b) **Cleistogamy**—This condition helps in self pollination in such flowers which never open. These are known as *cleistogamous* flowers. These flowers are bisexual, very small, inconspicuous, colourless and do not secrete nectar or honey, *e.g.* *Oxalis*, *Viola*, groundnut and *Commelina bengalensis*. In groundnut and *C. bengalensis* the flowers are borne on the underground branches.

Advantages of Self-pollination

(i) Less chances of the failure of pollination.
(ii) Purity of the race is maintained.
(iii) Avoids wastage of pollen grains.

Disadvantages

(i) Continuance self-pollination results in the weaker progeny.
(ii) New species and varieties of plants are not produced.

2. Cross-pollination

The process of transference of pollen grains on the stigma of another flower, the two being borne by two separate plants of the same or allied species is known as *cross-pollination*. In plants it is much more common than self-pollination. The flowers adopt many and various adaptations to achieve cross-pollination through the external agents. The agents responsible for cross-pollination are insects, animals, wind, water, etc., and are placed under the following groups—

(a) *Wind-pollination or Anemophily*
(b) *Insect-pollination or Entomophily*
(c) *Water-pollination or Hydrophily*
(d) *Animal-pollination or Zoophily*

(a) **Anemophily**—When the flowers are pollinated by wind agency, the phenomenon is known as *anemophily*. The wind-loving flowers are provided with the following characters:—

(i) Flowers are colourless, inconspicuous and small, without fragrance and nectar.

(ii) Pollen grains are produced in large quantities to ensure pollination. Calyx and corolla may be reduced.

(iii) The pollen grains are light, dry and sometimes winged so that they are easily carried away by wind.

(iv) The stigmas are usually branched, broad, large, well-exposed, and hairy to catch the pollen from the air.

(v) When flowers are unisexual, the staminate flowers are much more numerous than the pistillate ones.

(vi) In certain cases, *e.g.* silk cotton, flowers are produced before the appearance of leaves. This increases the chances of pollen grains reaching the stigma.

The common examples of wind-pollinated flowers are grasses, sugarcane, bamboo, sedges, etc.

(b) **Entomophily**—When pollination is brought about by the agency of insects, it is known as *entomophily* or *insect pollination*. The chief pollinating insects are bees, butterflies, moths, flies and beetles. The flowers relying on insects for pollination have the following principal adaptations :—

(i) The flowers are usually large, conspicuous and brightly coloured so that insects can be attracted from long distance, *e.g.* rose, holyhock, sunflower, etc.

(ii) The sepals and petals are well developed, showy and attractive. Sometimes, the petals

become more brighter and develop peculiar shapes to attract the insects.

(iii) The insect-loving plants often have a pleasant scent and sweet nectar. Most of the nocturnal flowers are insect-loving, and they give out a sweet smell at night. This sweet smell attracts insects from a distance. Common examples are jasmine, rose and Rangoon creeper.

The flowers with gamopetalous corolla secrete a sweet nectar which attracts insects like bees. The nectar secreting glands on nectaries are situated on the receptacle or on the spurs (petals) at the base of the floral whorls. When the bees collect nectar from the nectaries, they incidently bring about pollination.

(iv) Pollen grains are usually rough and sticky and often provided with spinous outgrowths so that they can easily stick to the bodies of visiting insects.

(v) The stigma is also sticky and rough and thus catches the pollens soon and easily.

(vi) In many cases the pollens are edible and offer additional attraction to the insects as in poppy and rose.

(vii) When the flowers are small and inconspicuous, other parts become enlarged, coloured and showy. In *Bouganvillea*, the bracts are brightly coloured. In *Euphorbia splenedus*, the bracts of each cyathium become deep red in colour. In *Poinsettia*, leaves in floral region become wholly or partly coloured.

(viii) When the flowers are small and inconspicuous, they are condensed together to form a head as in sunflower. In such cases, a single insect brings about pollination in a large number of flowers.

(ix) The insect-pollinated flowers usually blossom at a time when the particular insects are also available.

(c) **Hydrophily**—When the pollination takes place through the agency of water, it is known as hydrophily. It is common in aquatic plants where the flowers are borne at the surface of the water, *e.g.*, *Vallisneria*, *Hydrilla*, etc. Pollination is brought about by the movement of water which brings the anthers of male flowers against stigmas.

In *Vallisneria*, the plants are dioecious *i.e.*, staminate and pistillate flowers are borne on distinct plants. The male flowers are small, short-stalked, and are produced in large numbers. These flowers are surrounded by a spathe under water. The female flowers on the other hand, are solitary and are borne on long and coiled stalks.

On maturing, male flowers get detached from the parent plant and float on the surface of water owing to the opening of the perianth into a boat-like structure. At the same time female flowers rise to the surface of water by the straightening of stalk. As the anthers come in contact with stigma, they dehisce and some of the pollens stick to the stigma. After pollination, the long stalks of the female flowers curl up and draw them below the surface of water down in the mud where the seeds and fruits ripen.

(d) **Zoophily**—Birds, squirrels, bats, snails, etc., also act as useful agents of pollination. Birds and squirrels bring about pollination in *Bombax*, *Anthocephalus*, etc. Snails bring about the pollination in certain aroids and snake plant. These animals do so when they run from plant to plant in search of food.

Advantages of Cross-pollination

(i) Cross-pollination results in healthy and stronger offsprings.

(ii) It results in the production of large number of seeds.

(iii) New varieties with useful characters are produced.

(iv) Cross-pollination has been utilized in improving the crops and for the development of new kinds of vegetables and fruits.

Disadvantages

(i) As cross-pollination is brought about by external agents, it is more or less precarious.

(ii) The plant requires lot of energy and food material to adopt various devices to bring about pollination.

Contrivances Governing Cross Pollination

The plants develop numerous devices which prevent self-pollination but facilitate cross-pollination. These are as follows :—

(a) **Unisexuality**—In this case the flowers are usually unisexual. Male and female flowers may

be borne separately on distinct platns, *e.g.*, mulberry, hemp, betel or on one plant, *e.g.*, maize, castor, *Euphorbia*, etc.

(b) **Dichogamy**—In many hermaphrodite or bisexual flowers the anther and stigma mature at different times and thus avoid self-pollination. This condition is known as *dichogamy*. When the stamens mature earlier than the stigma it is known as *protandry* and the flowers are called *protandrous e.g., Coriander*, jasmine, sunflower, etc. The reverse of above that is when stigma matures earlier than the stamens, it is known as *protogyny* and the flowers are called *protogynous*, *e.g.*, rose, tobacco, crucifers, etc.

(c) **Self-sterility** –In this condition, the pollen of one flower cannot fertilize the eggs of the same flower. The common examples of self-sterile flowers are tea flowers and some varieties of passion flowres. In these flowers cross-pollination is the only means for fertilization and production of seed.

(d) **Herkogamy**—In some bisexual flowers where the stigma and anthers mature at the same time, self-pollination is avoided by some sort of barrier. The flowers show following contrivances:—

(i) The male and female sex organs lie at some distance from each other.

(ii) In some flowers corolla has peculiar forms which act as barrier in self-pollination, *e.g.*, *Aristolochia*.

(iii) In some other flowers, the pollens are held together to form pollinia which can only be carried away by insects, *e.g.*, orchids and *Calotropis*.

(e) **Heterostyly**—Heterostyly is a special device to ensure cross-pollination in those plants, where male and female organs mature at the same time, *e.g.*, prime-rose, *Oxalis*, etc.

The plants of some species bear flowers of two different types. Some of them possess a long style but short stamens and are known as the *pin-eyed* while others have short styles and long stamens. These are known as *thrum eyed*.

FERTILIZATION

Fertilization is the process of fusion of two dissimilar sexual reproductive units called gamets *i.e.*, the fusion of male gamete with the egg of the ovule.

After pollination, *i.e.*, when a pollen grains reaches stigma, it absorbs moisture and swells. It results in the rupture of the exine at certain thin or weak points called *germ pores*. The intine grows out in the form of a tube called the *pollen tube*. The contents of the pollen grain or the microspore including both the nucleus and generative nucleus migrate to the distal end of the pollen tube.

The pollen tube gradually elongates and pierces its way through the style into the cavity of the ovary. From here it grows and moves towards the micropyle of the ovule. Sometimes, the pollen tube penetrates ovule at the chalazal end. Fertilization is said to be *porogamous* when the pollen tube enters through the micropyle and it is known as *chalazogamous* when it enters through the chalazal end. By this time generative nucleus divides to give two equal, non-motile gametes and the vegetative nucleus disintegrates.
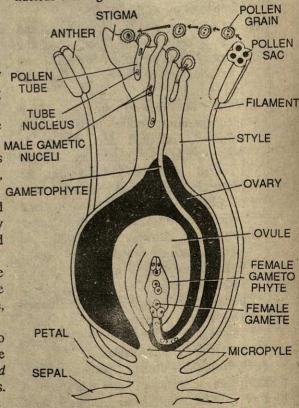
Fig. 9.16 L.S. ovary showing the process of fertilization.

The fully developed embryo-sac at this stage consists of three antipodal cells, two synergids, one egg cell and one secondary nucleus. The pollen tube pierces through the nucleus and finally penetrates the wall of the embryo sac. The tip of

the pollen tube disintegrates and the two male gametes are set free in the embryo sac. The two synergids which help in directing the pollen tube towards the egg disintegrate. Of the two male gametes, one fuses with the oosphere and the other with the secondary nucleus or the polar nuclei. The fertilized egg now becomes the oospore or the zygote. It secretes a wall around it and is diploid in structure. This type of fusion is known as *syngamy* or *fertilization*. The second male gamete and the polar nuclei or the secondary nucleus fuse to form *primary endosperm nucleus*, which is the result of *triple fusion*. The triple fusion along with the fertilization of the egg is known as *double fertilization*.

As the antipodal cells have no special function they perish after fertilization. The oospore develops into the embryo proper and the endosperm nucleus gives rise to the endosperm.

SEED FORMATION

After fertilization the oospore or zygote undergoes a period of rest. Then a series of changes take place which lead to the formation of seed from the ovule and of fruit from the ovary. The changes can be grouped as follows—

1. *Embryo formation*
2. *Endosperm formation*
3. *Seed formation*

1. Embryo formation—The zygote or the oospore secretes a cell wall made up of cellulose and divides by a transverse wall into an upper *suspensor cell* and a lower *embryonal cell*. The suspensor cell which lies towards the micropylar end, divides transversely to form a row of seven to eight cells, the *suspensor*. The suspensor pushes the developing embryo deep into the embryo sac where the endosperm is developing. The basal or the terminal cell of the suspensor attached at the micropylar end enlarges and becomes oval or spherical in shape. It serves to absorb food material. The lowermost cell of the suspensor adjacent to the embryonal cell is known as *hypophysis*. It forms the *apex* of the radicle or the primary root.

Meanwhile, the embryonal cell divides thrice to give rise to an eight-celled octant or embryonal mass, the first two divisions are vertical and the third one being the transverse division. The four terminal octants or the outer four cells form the

plumble and the *cotyledons*. The four basal octants towards the suspensor form the *hypocotyl* and the *pleurome* of the *radicle*, the growing point of the radicle developing from the hypophysis as mentioned above. By further repeated divisions, these embryonal cells form spherical mass which later on becomes heart-shaped. The two lobes continue to grow by further divisions into the two cotyledons. A group of cells in the groove of the two lobes forms the plumule and the suspensor disintegrates.

Unlike the dicots, where the embryonal mass is formed of eight cells, the four anterior cells forming the plumule and the cotyledons and the posterior octants forming the hypocotyl, the development is very much variable in monocots. In certain cases, suspensor does not develop at all. There is a single cotyledon arising as a terminal structure. The plumule always arises laterally from it.
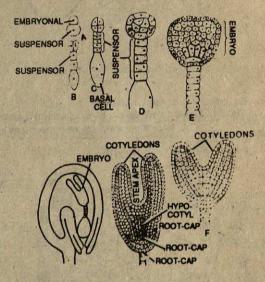
Fig. 9.17 Different stages in the development of embryo (dicot)

2. Formation of Endosperm—While the development of the embryo is going on, the primary endosperm nucleus also starts dividing. The triploid or the primary endosperm nucleus is formed as a result of the fusion of two polar nuclei and a sperm nucleus. Thus it has 3N number of chromosomes.

As a result of a number of successive and repeated divisions, several nuclei are formed which
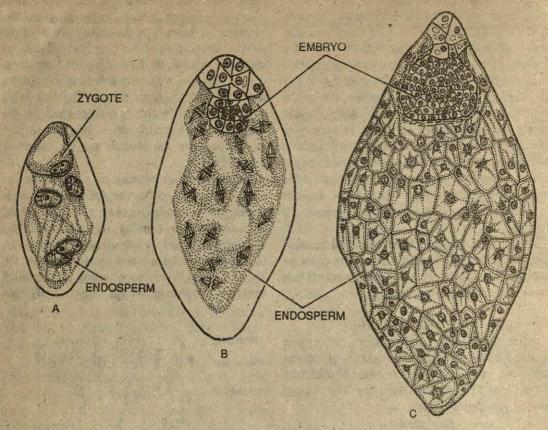
Fig. 9.18 Stages in the development of nuclear endosperm in *Acalypha indica*. A-B. free nuclear stages. C.A later stage when the endosperm has become cellular.
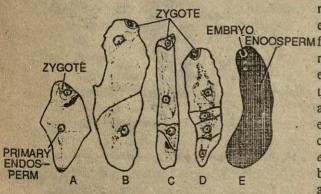
Fig. 9.19 Stages in the development of cellular endosperm in Drimys winteri. A. Embryo sac before the division of the primary endosperm nucleus B-D. 2, 3 and four celled endosperm. E. Endosperm at the globular stage of embryo development.

lie freely in the cytoplasm. Now the walls are laid around them and a multicellular tissue called the endosperm is formed. It contains lot of reserve food material and serves as a storage tissue for the embryo. The endosperm receives its food supply from the nucleus which ultimately perishes and remains in the form of a thin layer outside the endosperm and is known as *perisperm*. In most of the dicotyledons, the cotyledons become fleshy by absorbing food from the nucellus and the endosperm. In such cases endosperm disappears completely. Such seeds are known as *non-endospermic* or *ex-albuminous, e.g.* gram, almond, bean etc. In monocots the endosperm persists as a permanent tissue and such seeds are called *endospermic* or *albuminous, e.g.* castor seed, piazi, maize, *Triticum*, etc.

In angiosperms endosperm develops in three different ways—*nuclear, cellular* and *helobial*.

1. Nuclear type. This is the most common type of endosperm development. Here, the endosperm nucleus gives rise to a number of free nuclei which remain in the peripheral layer and a large central

vacuole appears in the embryo sac. Finally cell wall formation takes place from the periphery of the embryo sac towards the centre leading to the formation of cellular endosperm.

2. Cellular type. In a number of plants such as *Adoxa, Peperomia, Villarsia* and *Drimys*, division of the primary endosperm nucleus is immediately followed by wall formation so that the endosperm is cellular from the beginning.

Fate of different parts of flower during fruit formation after fertilization

Floral Parts	Fate in Fruit
I. Accessory Parts	
1. Sepals	Fall off
2. Petals	Fall off
3. Stamenus	Fall after dehiscences of
4. Style and stigma	Fall off
II. Main Parts	
1. Ovary	Forms fruit
2. Ovary wall	Pericarp (fruit wall)
3. Ovule	Seed
(i) Funicle	Stalk of the seed
(ii) Hilum	Hilum
(iii) Nucellus	Perisperm
(iv) Outer integument	Testa (outer seed coat)
(v) Inner integument	Tegmen (inner seed coat)
(vi) Micropyle	Micropyle
4. Embryo Sac	
(i) Synergids	Are destroyed
(ii) Egg cell	Embryo
(iii) Antipodal cells	
(iv) Secondary nucleus	Endosperm

3. Helobial type. This is found in *Vallisneria, Eremurus* and *Limnophyton*. In this case endosperm development is intermediate between the nuclear and the cellular types. A partition wall develops between the two nuclei resulting from the first division of the endosperm. A large number of free nuclei is now developed in the upper chamber while the lower nucleus forms a few of them or may not divide at all.

3. Formation of seed—As a result of stimulus from fertilization a number of changes occur in the tissue outside the embryo-sac leading to the formation of seed. The ovule increases greatly in size. The integuments dry up. The outer one becomes hard or leathery and forms the outer seed coat or *testa* while the inner one if persists forms the *tegmen*. During development the nucleus is used up and totally disappears, but in certain cases

it persists in the form of a food storing thin layer and is known as *perisperm*. The endosperm may persist or may be used up by the embryo before seed formation leaving its remanants only. A scar is usually visible on one side of the outer seed coat.
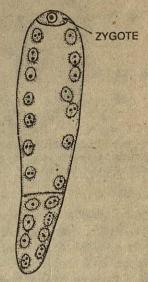
Fig. 9.20 Helobial type of endosperm development in *Eremurus*.

It is known as *hilum*, and marks the point of attachment to the stalk. With these changes the ovule changes into the seed and enters a period of dormancy, while the ovary ripens into a *fruit*.

FRUIT

Fruit may be defined as a mature or ripened ovary. The stimulus of fertilization not only develops ovules into seeds but also brings about other changes in the flower. Usually, all the parts of the flower except the ovary wither away. The ovary begins to enlarge simultaneously with the development of the seed and ultimately becomes the fruit.

True fruit and False fruit

A true fruit is one which develops from a single ovary of a single flower with no other part outside the ovary e.g. mango. A fruit is *false* or *spurious* (pseudocarp) when other floral parts also take part in the formation of fruit. All *aggregate* and *multiple* fruits are false. Fruits resulting from inferior ovaries are false as the wall of such an ovary has a part of thalamus fused with it. Fruits of apple and pear of false as the edible part is

mainly fleshy thalamus. *Brinjal* is false as it has a persistent calyx. Likewise, *strawberries* and *figs* are also false fruits.
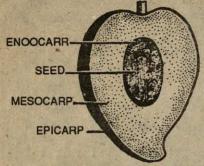
Fig. 9.21 A fruit of mango cut open to show the massive mesocarp surrounded on the outside by a thin epicarp and on the inside by the hard endocarp.

Structure of Fruit

A fruit has a wall or *pericarp* which develops from the wall of the ovary. When well developed, it shows three layers—an outer *epicarp*, a middle *mesocarp* and an inner *endocarp*.

In mango, the outer, thin and leathary part is the epicarp. The sweet fleshy part that is eaten constitutes the *mesocarp*, and the innermost hard zone that encloses the seed is the endocarp. The nature of these zones varies in different fruits. In dry fruits, the pericarp is papery or woody and is not distinguishable into three zones.

DEVELOPMENT OF FRUIT

During the development of flower, ovary is the last organ to differentiate. At the time of flower opening (anthesis), all the parts of flower *viz.* sepals, petals and stamens are mature but the ovary is partially matured. It is only after the stimulus of pollination that the ovary starts further development.

Role of Pollination in Fruit Development

Pollination has an important role in fruit development. It contributes to fruit development in the following ways—(1) It is essential for fertilization and ultimately for seed formation. (2) It prevents ovary abscission. (3) It stimualtes the growth of ovary to become fruit.

Role of Seeds in Fruit Development

It has been proved experimentally that pollen contains small amount of auxin. This auxin together with a limited amount of additional auxins present in the carpellary tissues can support only limited growth of the ovary. Further growth of ovary into fruit depends on the development of normal seeds which synthesise auxins, gibberellins and cytokinins. Thus, it can be inferred that seeds play a key role in fruit development. In the absence of seeds, fruits can be developed by applying small amounts of auxins.

Nitsch Experiment to show Role of Seed in Fruit Development

NITSCH performed several experiments on strawberries to demonstrate the importance of
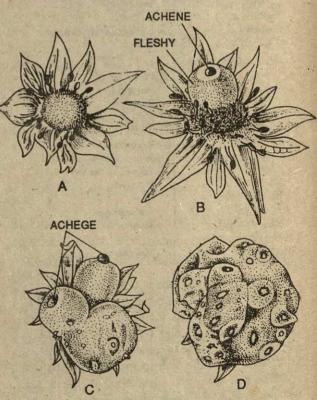
Fig. 9.2.2 Experiment of Nitsch to demonstrate the effect of developing seeds on the growth of strawberry fruit. In this fruit succulent part is derived from the receptacle and the single seeded fruits are embedded on its surface. Seed development can be suppressed by avoiding pollination. A-Unpollinated flower: the receptacle has not developed at all. B-Only one carpel was pollinated, the receptacle grows only around the pollinated carpel. C-Serveral seeds and correspondingly several areas of receptacular growth are seen. D-The number of seeds developed higher than in C and receptacle is approaching the shape of abnormal strawberry fruit.

seeds in fruit development. Strawberries are an example of aggregate fruits developing from a single flower with multiple gynoecium. The edible part is the fleshy receptacle and the small seeds which represent the individual fruits are arranged on its surface. When in a young strawberry, all the carpels are removed within nine days after pollination, the receptacle does not grow at all. On the other hand if only a few carpels are retained here and there, the fleshy tissue develops only around them. Now NITSCH selectively removed some carpels and obtained strawberries of curious shapes. This was because of the fact that receptacle did not grow in the regions where from pollinated carpels were removed.

The role of seeds in fruit development could also be demonstrated by selective pollination of some carpels because unpollinated carpels do not form seeds. However, normal fruit development could be induced even after removing the carpels or completely avoiding pollination by applying small amounts of auxin.

The development of a fruit involves both cell division and cell expansion. After fertilization the ovary shows rapid growth. In pumpkin, ovary increases 20-fold in about 2 weeks time.

It is seen that all the flowers borne on a plant do not mature into fruits. In apple and mango, for example, fruit-set is extremely low as compared to the total number of flowers formed. The shedding of flowers may occur before or after anthesis. This is called *flower thinning*. In certain cases even immature fruits may drop. This is called *dune drop*. Application of auxins has been found useful in controlling flower thinning and dune-drop. However, dropping of flowers and young fruits is of much significance to the cultivators because it results in the production of fruits of larger size. In apples, pears and plums, flowers thinning by hormonal spray is a regular practice.

Ripening of Fruit

Fruit ripening is the last event in the development of fruit. As soon as the growth of the ovary wall due to cell division and cell enlargement ceases the fruit is said to be mature.

This is followed by fruit ripening. This stage is characterized by the conversion of starch into sugar, reduction in the concentration of acids and the production of esters. The breakdown of chlorophyll leads to changes in colour, texture, taste and flavour of the fruit. A mature fruit of mango is hard and green with its edible portion being white and sour. On ripening, the mesocarp becomes yellow-orange, juicy and sweet. In certain fruits like banana, ripening is characterized by an increase in the respiratory rate. This is known as *climacteric*. This is followed by decaying which leads to death.

Parthenocarpy

The fruit is usually developed by the stimulus of fertilization but in some plants fruits are formed without fertilization. Such fruits are called *parthenocarpic* and the phenomenon is known as *parthenocarpy*. Parthenocarpic fruits are either seedless or contain empty or non-viable seeds. In these fruits stimulus for fruit growth is provided by the tissue of the ovary wall itself. Seedless varieties of grapes and oranges contain upto seven times as much auxin in the ovaries than the seeded varieties. Natural parthenocarpy is found in oranges, cucumbers and seedless grapes. Most commonly cultivated varieties of banana and pineapple are parthenocarpic. Even in seeded varieties of fruits, parthenocarpy can be induced by the application of low concentrations of auxin and gibberellin.

Parthenocarpy is of great commercial value. World's best varieties of fruits like banana, pineapples, grapes, etc. are parthenocarpic. Seedless tomatoes may be produced parthenocarpically in the green house. The use of hormones to increase the fruit yield of a number of plants that are not easily pollinated, is a practical possibility. Parthenocarpic fruits are ideal for consumption as such, in the preparation of jams and fruit juices on a commercial scale.

Biological Significance of Fruit Formation

Fruits are in use since the prehistoric times as the main food of man. Even today fruits comprise main part of the human diet. But fruit formation has its own significance for the plant.

1. Fruit protects the immature seeds from unfavourable environmental conditions. The seeds remain enclosed in the fruit until they are ready to germinate.

2. The fruit wall also helps in seed protection because of its colour. When young most

fruits are green, and remain nidden in the foliage.

3. The immature fruits offer chemical defence against the animals because they contain unpalatable and repelling substances like astringents, tannins, sour acids and bitter alkaloids.

4. Mature fruits acquire bright colours to attract the seed-dispersing animals.

5. Certain fruits on maturity burst with great pressure so that the seeds are dispersed to a distance.

Classification of Fruits

The fruits can be grouped and classified into the following three categories—

1. Simple fruits
2. Aggregate fruits
3. Multiple fruits.

1. Simple Fruits

These are the fruits which develop from a single flower having a *monocarpellary* or *polycarpellary* and *syncarpous ovary* with or without accessory parts. They are of the following types : --

(A) Dry fruits

(B) Succulent fruits

(A) **Dry fruits** In dry fruits the pericarp is leathery, hard and papery. Depending upon
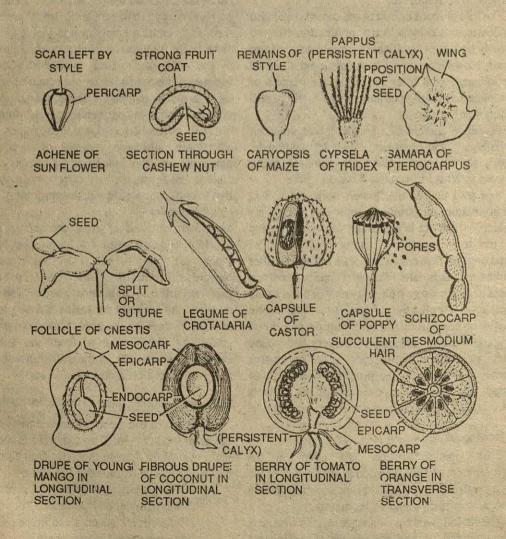
Fig. 9.23 Different types of fruits.

whether the fruit opens or not to discharge its seeds the dry fruits are classified as *dehiscent* and *indehiscent.*

(a) **Indehiscent fruits**—These fruits have no mechanism to split and disperse the seeds. These are of the following types.

(i) **Achene** is the simplest indehiscent fruit which consists of one seed surrounded by a dry pericarp which does not dehisce, *e.g.* Sunflower.

(ii) **Nut** is similar to achene but the pericarp is hard and stony, and separated from the seed coat, *e.g.* Trapa and cashew nut.

(iii) **Caryopsis** is an achene-like fruit in which the pericarp and seed coat have become fused together. It is found in *maize, wheat, barley* etc.

(iv) **Cypsela** is an achene in which the seed is provided with a crown of pappus *e.g. Dandelion, Tridex.*

(v) **Samara** is an achene in which the pericarp has extended to form one or more wings, *e.g. Pterocarpus.*

(b) **Dehiscent fruits**—Such fruits dehisce by longitudinal seeds or pores to disperse the seeds. They are of the following types :

(i) **Follicle** is a dry fruit formed from one carpel and splits open on one side only, *e.g. nestis, madar, ak* and *larkspur.*

(ii) **Legume** is a dry fruit with many seeds. It splits open from both the sides, *e.g. pea, bean,* etc.

(iii) **Capsule** is a dry fruit formed from two or more carpels which contains many seeds. It may dehisce in different ways. For example, the capsules of castor and cotton open by longitudinal slits, while poppy seeds are set free through rings of pores just below the tip of the capsule.

(iv) **Schizocarp** is a dry, many seeded fruit which breaks up into several parts each containing one seed. It is found in *Desmodium* and babul.

(B) **Fleshy fruits**—In these fruits at least part of the fruit is fleshy and eaten. The fruit wall or *epicarp* has three parts—the outer *epicarp,* the middle *mesocarp,* and the inner *endocarp.* The main group of fleshy fruits are the *berries,* the *drupes,* and the *pomes.*

(i) **Berry**—In berry the fruit wall (pericarp) is fleshy and the whole fruit is eaten. *Tomato* and *guava* are common examples. *Orange* is a special type of berry, called the hesperidium, in which hairs attached to the skin-like endocarp have become succulent and juicy. Banana also is a berry,

but seeds are found only in wild varieties. In the dates pericarp is soft and the stone is formed by the seed coat.

(ii) **Drupe**—In the drupe the endocarp of the fruit wall is hard and stony. Examples are the mango, *Indian almond* and *coconut.*

In *mango,* the mesocarp is juicy, while in the *coconut* and the Indian almond, the mesocarp is fibrous.

(iii) **Pome**—A pome is a false fruit consisting of juicy, swollen receptacle surrounding the pericarp which is still and not edible. The true fruit formed from the ovary is hidden inside the fleshy receptacle as in *apple* and *pear.*

2. Aggregate Fruits

An aggregate fruit is formed from a single flower which has several carpels, and is, therefore, a collection of simple fruits, *e.g.* the lotus, rose fruit and starwberry are a collection of achenes; raspberry, a collection of drupes and custard-apple is a collection of berries.

3. Multiple Fruits

A multiple fruit develops from an inflorescence where the flowers are crowded together. They are of the following types :

(a) **Sorosis:**—This is a multiple fruit in which flowers fuse together by their succulent sepals and the axis bearing them becomes fleshy and swollen as in pineapple, jack fruit and mulberry.

(b) **Syconous:**—It develops from the peduncle of the inflorescence, which is greatly enlarged and contains a cavity. Inside the hollow cavity, the male and female flowers develop, and later the female flowers ripen into small drupes as in fig. 9.22.

Table 9.2 Some common fruits and their edible parts

S.No.	Name of the Fruit	Edible Part
1.	Apple	Fleshy thalamus
2.	Almond	Seed
3.	Banana	Mesocarp and Endocarp
4.	Coconut	Endocarp
5.	Cucumber	Placenta, seeds and pericarp
6.	Custard-apple	Pericarp
7.	Grape	Pericarp
8.	Bean	Cotyledous of the seed
9.	Guava	Thalamus and pericarp
10.	Jackfruit	Bracts, perianth and seeds

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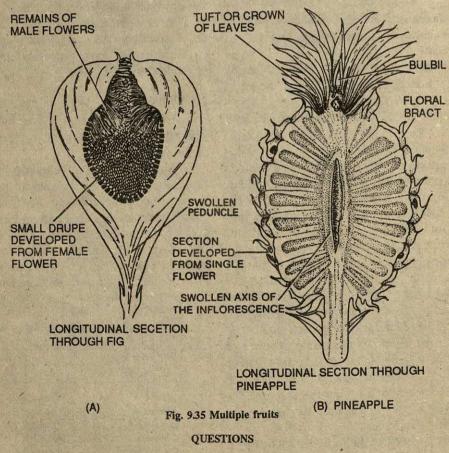
11.	Lemon and orange	Juicy glandular hairs arising from the endocarp
12.	Litchi	Aril
13.	Maize	Endosperm
14.	Mango	Mesocarp
15.	Melon	Mesocarp
16.	Mulberry	Peduncle and perianth
17.	Papaya	Mesocarp
18.	Pea	Cotyledons of the seeds
19.	Pineapple	Receptacle, perianth and bracts
20.	Pomegranate	Fleshy and juicy seeds
21.	Pear	Thalamus
22.	Strawberry	Thalamus
23.	Tomato	Whole fruit
24.	Water melon	Mesocarp
25.	Walnut	Seed
26.	Wheat	Endosperm

Significance of the Study of Fruits

The study of fruits is important to understand the distribution, adaptation, evolution, taxonomy and utilisation of plants.

The morphology of seed and fruit is an important criterion for classification and phylogeny of plants.

Pomology is the branch of horticulture that deals with the study of fruits, their improvement and cultivation.

Fig. 9.35 Multiple fruits

(A) — REMAINS OF MALE FLOWERS, SMALL DRUPE DEVELOPED FROM FEMALE FLOWER, SWOLLEN PEDUNCLE, LONGITUDINAL SECTION THROUGH FIG

(B) PINEAPPLE — TUFT OR CROWN OF LEAVES, BULBIL, FLORAL BRACT, SECTION DEVELOPED FROM SINGLE FLOWER, SWOLLEN AXIS OF THE INFLORESCENCE, LONGITUDINAL SECTION THROUGH PINEAPPLE

QUESTIONS

1. What is double fertilization? What is its significance?
2. Write a concise account of endosperm development.
3. With the help of suitable diagrams, compare the structure of male and female gametophytes.
4. Compare the male gametophyte of pine with that of an angiosperm.

5. What is pollination? Describe the contrivances found in plants for cross pollination.
6. Write an essay on pollination in plants.
7. Describe the adaptations that promote cross pollination in bisexual flowers.
8. What is microsporogenesis? Where does it occur in angiosperms? What is its significance?
9. Stage the factors responsible for the development of a fruit.
10. What is endosperm and what is its function?
11. Write short notes on the following—
    (a) Endosperm   (b) Double fertilization
    (c) Triple Fusion   (d) Embryo sac
    (e) Pollination.
12. Describe the structure of ovule as seen in longitudinal section.
13. Write a concise account of different types of endosperm development.
14. Draw a transverse section of young anther to show various structures.
15. Give reasons for the following—
    (a) Cross-pollination is considered to be superior or self-pollination.
    (b) Flowers of some plants are bright and showy while those of some others are very small and inconspicuous.
    (c) Cliestogamy is considered to be the most effective device for self-pollination.
16. Distinguish the following—
    (a) Endospermic and non endospermic seeds
    (b) Self and cross-pollination
    (c) Entomophilous and anemophilous flowers.

Reproduction and Development in Plants

The life of an individual plant is limited in duration. In order to continue the perpetuation of the species and also to multiply in number the plants have developed certain mechanisms by which they can reproduce. Following are the principal methods of reproduction in plants—

1. Vegetative Reproduction
2. Asexual Reproduction
3. Sexual Reproduction

1. Vegetative Reproduction

Vegetative reproduction is the process of multiplication in which a portion of the plant body becomes detached and develops into a new plant. It takes place by following methods :—

A. Natural Methods of Vegetative Propagation

Vegetative propagation takes place by the following methods—

1. Fragmentation—In certain filamentous algae like *Ulothris* and *Spirogyra* mechanical injury or the death of certain cells results in the breaking up of the filament into two or more portions, each of which grows into an independent plant.

2. Budding—It is found in yeasts and certain bacteria. In budding one of the cells formed as a result of cell division is considerably smaller than the other cell and is regarded as the daughter cell.
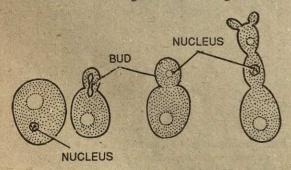
Fig. 10.1 Budding in yeast

The daughter cell separates from the parent cell and gradually attains full size. Sometimes, even before the daughter cell becomes detached from parent cell, it may start forming bud thus forming a filament.

3. Gemmae—In some mosses and liverworts, *e.g. Marchantia,* special bodies known as *gemmae* develop on the leaf, branch or thallus for the purpose of vegetative propagation.

Among the flowering plants, a number of herbaceous and perennial plants propagate vegetatively in nature. Roots, stem, leaves and buds are the common structures that take part in vegetative propagation.

1. Roots—The tap roots of carrot, radish and the adventitious roots of *Asparagus, Dahlia,* sweet potato, etc. serve to propagate plants vegetatively. Root cuttings of raspberries, poppies and black berries are also used in vegetative propagation.

2. Underground stems—Plants possessing underground stems such as rhizome, tuber, corm and bulb are provided with buds which develop into new plants.

Ginger, Canna and Iris are propagated by cutting the rhizomes into pieces, each piece bearing a well-developed bud.

As a commercial practice, potato crop is raised by tubers and not by seeds. Before planting, potato tubers are cut into small pieces such that each piece has atleast one eye. The central bud of each eye develops into a shoot which shortly produces adventitious buds.

Bulbs of onion and lillies when planted develop roots and shoots from the nodes. These increase in number by producing smaller bulbs in the axils of outer leaves. When mature, these may be removed and planted to grow flowering sized bulbs.

Crocus and *Gladiolus* are grown vegetatively
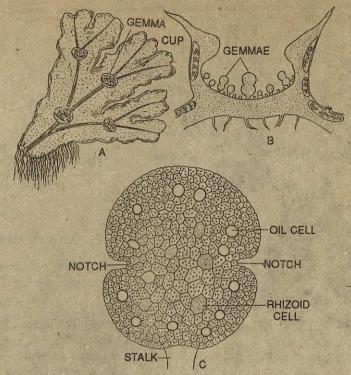
Fig. 10.2 Marchantia. A. Thalius showing the gemma cups. B. Vertical section of a gemma cup showing gemmae. C. A single gemma highly magnified.
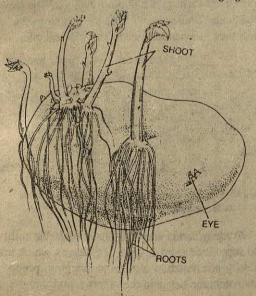
Fig. 10.3 A sprouted potato tuber showing the development of many plants.

at the bases of the new shoots that arise from the old corm.

The commercial varieties of banana produce no seeds and are propagated by the corm and suckers or lateral shoots that arise from buds on the corm. The stem of the banana plants arises from a huge, tuber-like corm. When a new plantation is started, the corm is cut into pieces, each bearing atleast one eye or bud. These are planted about a foot deep in rows. After a few weeks, a shoot appears above the ground and grows for 7-10 months before the flower stalk appears. During this time the base of the shoot enlarges into a corm.

Typha propagates vegetatively with the help of rhizome. The rhizome of *Typha* grows in the mud developing several nodes on its body. The apex behaves as shoot apex and emerges out of the ground in the form of an erect stem. At the base of the rhizome many buds develop which eventually give rise to leafy shoots. The growth in *Typha* is so vigorous that in no time it covers miles of marshy lands. Likewise a single plant of water hyacinth produces more than 65000 plants

with the help of corms. When a corm of *Gladiolus* is planted, one to three new corms are produced

Fig. 10.4 A. Bulb of onion
B. L.S. of bulb
C. Corm of Crocus.

plants.

4. Leaves—The leaves of most plants do not produce new plants, but in certain plants leaves also take part in vegetative propagation.

In walking ferns, when the tips of older leaves come in contact with damp soil, the adventitious roots may form and a shoot develops. The new plant thus "walks away" from the parent plant and becomes independent when the old leaf dies.
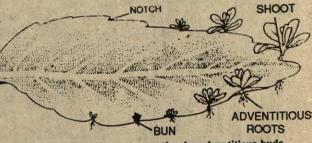
Fig. 10.6 Vegetative propogation by adventitious buds in the margins of leaves in *Bryophyllum*.

Fig. 10.5 A runner of the mint plant bearing numerous adventitious roots and a shoot at each node.

in just one growing season of about 8 months.

3. Subaerial stems—In many plants, sub-aerial parts are modified to reproduce vegetatively. The runner of *Cynodon*, stolon of *Alocasia*, sucker of mint and offset of *Pistia* develop adventitious roots and aerial shoots at the nodes. On getting detached from the parent plant, these develop into new

Bryophyllum is known for its remarkable ability to reproduce from leaves. The leaves which are fleshy and notched along the margins, produce meristematic tissue in the notches, and this tissue gives rise to tiny plants. The plantlets are produced while the leaf is still attached to the parent plant. These young plants have tiny leaves, stems and buds. These eventually fall off and grow to form new plants. In propagation by leaves, either the entire leaf is taken or the leaf is cut into pieces
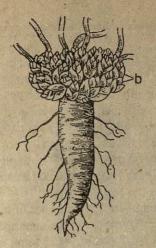
Fig. 10.7 Bulbil of Oxalis.

Fig. 10.8 Layering.

and the notched pieces are then planted. *Begonia*, *Glocinia* and African violet are other plants that are propagated by leaves.

5. **Bulbils**—These are multicellular, more or less spherical structures produced in the axil of foliage leaves in place of buds. These bulbils sooner or later shed from the parent plant and on getting favourable conditions develop into a new plant. In some cases floral buds are also modified into bulbils. *Oxalis, Allivus sativum, Aloe*, etc. are common examples of bulbils.

B. Artifical Vegetative Propagation

Vegetative propagation by artificial means may be brought about by the following methods—

1. **Layering**—In lemon, rose, jasmine, strawberry, raspberry, grape-vine, etc., the lower branch is bent down and covered under a light layer of moist soil by pushing the tip into the soft ground. After some time, adventitious roots develop and on cutting the branches from the parent plant, these develop into new plants. This is known as *layering*.

In those plants where the branches cannot be bent to the ground, method of air-layering is adopted. In this case from a portion of a branch the bark is removed, and it is covered with mosit moss and enclosed in a polythene bag. When roots apear, the stem is cut below the level of roots and planted.

2. **Cutting**—Several plants like sugar-cane, rose, *Duranta, Coleus,* and China-rose, etc., are grown from stem-cutting. For this type of vegetative propagation, the shoots should be more than one year old and the period of vigorous growth is the most suitable time for the cuttings. When cuttings from such plants are put into the moist soil, they develop adventitious roots and buds at the base which develop into new plants.
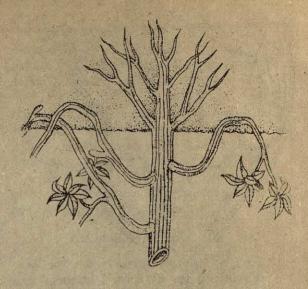
In *Citron* and *Tamarind* root cuttings are used for vegetative propagation. When the root-cuttings are put into moist soil, they sprout forming roots and shoots.

3. **Gootee**—It is a modified form of layering. In this case the cut or injured branch is not burried in the ground but is bound with mud and rags, etc. which is kept moist with the help of water kept in an earthen pot. The roots develop at this portion within a period of about a month or two. Now the branch is cut and separated from the parent plant from below the tied portion and is planted in the soil. This method is applied for the vegetative propagation of pomegranate, orange, lemon, guava, lokat and litchi, etc.

4. **Grafting**—In this case, a small branch of a plant is inserted into the stem of a rooted plant of the same or allied species. As a result of insertion, organic union or fusion of tissues takes place and both of them grow as one. The inserted plant is called the *scion*, the rooted plant is *stock* and the phenomenon as grafting.
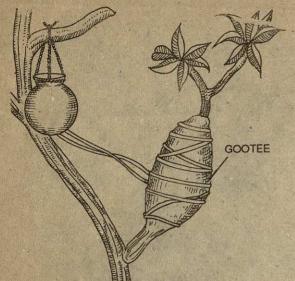
Fig. 10.9 Vegetative reproduction by gootee.

The scion is a shoot, 4 to 12 inches in length. Its all the buds are kept intact while all the buds of the stock are removed. The graft is placed on the stock and the joining portion is covered with a layer of wax or clay in order to prevent the evaporation of water and the entry of injurious bacteria. After some time the tissues of the graft and the stock become united. The grafting is of two types—
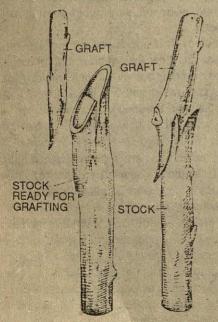
Fig. 10.10 Vegetative reproduction by grafting.

(i) *splice grafting*, and (ii) *whip grafting*. In splice grafting both graft and stock are cut across obliquely at about the same angle and then firmly tied together. In whip grafting both graft and stock are cut diagonally. Now a vertical cut notch is made in the stock and the graft is cut at one end to make a chiser-shaped structure or tongue. This tongue of the graft is inserted into the notch of the stock and the two are bound. In apple, citrus, mangoes, rose and lemon, new and superior plants are grown in this way.

5. Inarching—In it the branches of a superior plant and an inferior plant of the same species are chiseled and tied together. After some time, the inferior plant is separated from the superior plant.
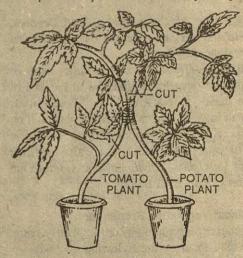
Fig. 10.11 Vegetative reproduction by inarching.

6. Budding—It is similar to grafting. In this method, instead of a branch with buds, a single bud along with a certain portion of the living tissue of the plant to be propagated is taken and inserted in a I-shaped incision made in the stock. Budding is usually done during the rainy season so that the bud may not dry up and die. After about 20 days, the bud germinates and becomes part of the new plant grown by budding (Fig. 10.12).

7. Micropropagation—This is the latest method of obtaining a number of plantlets from a small piece of plant tissue. This method is based on the tissue and cell culture technique.

For micropropagation, a small piece of tissue is excised from a plant and is growth in a nutrient medium under aseptic conditions. The tissue
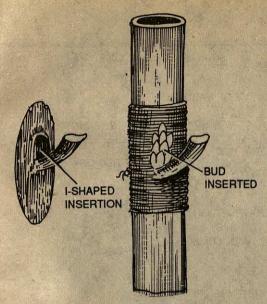
Fig. 10.12 Vegetative reproduction by budding.

proliferates into an undifferentiated mass called the *callus*. This callus can be kept and multiplied for an unlimited period. When small portions of the callus tissue are transferred to another medium, it induces the differentiation of plantlets. The plantlets are transplanted in pots or soil and raised to maturity. By this method an indefinite number of plants can be obtained from a small mass of parental tissue. Micropropagation has been found a great success in orchids, carnations, Freesias, chrysanthemums and Asparagus.

Micropropagation has also been helpful in obtaining virus-free potatoes, tulips, sugarcane etc. Usually, tissues of the shoot apices are virus-free even if the whole plant is infested with virus. By excising the shoot apices from the infected plants and then growing them on a nutrient medium, it is possible to grow virus-free plants.

Significance of Vegetative Propagation

1. Vegetative propagation is a more rapid, easier and cheaper method of propagating plants as compared to seeds. For example, certain lilies take 4-7 years from germination to flowering, whereas when grown vegetatively, they bear flowers within a year or two.

2. It is the only means of reproduction and perpetuation in those plants which do not form viable seeds. Bananas, figs, seedless grapes, pineapple, oranges, roses, chrysanthemums, jasmine, tulips, dahlias and carnation are propagated by this method only.

3. The most important advantage of vegetative reproduction is the preservation of the desirable characteristics in the plants, which is not possible in the plants raised from seeds as they may show variations due to genetic recombination and segregation. The genetically uniform population raised from a single plant is known as *clone*.

4. It is possible to raise a large stock of selected strains by vegetative propagation.

5. The desirable characters of fruits can be maintained in the progeny by raising the plants by means of vegetative propagation.

2. ASEXUAL REPRODUCTION

All processes of asexual reproduction involve only milotic cell division. The new cells have the same assortment of genetic information as did the mother cell. Asexual reproduction takes place by means of asexual reproductive units, called *spores*, produced by the mother plant, or sometimes by the fission of mother cell is the case of unicellular organisms.

1. **By fission**—In many unicellular algae and fungi and in bacteria, the mother cell splits into two daughter cells. The daughter cells soon grow to the size of the adult and behave as independent adult plant.

As a form of reproduction, the chief advantage of fission is its speed. A bacterial cell formed by fission is ready to divide and produce two new cells within 15-20 minutes. In a space of one hour three generations of bacteria arise to produce three generations of human beings, it would to be about 60 years.

2. **By spore formation**—Spores are asexual reproductive units which can grow independently. These are unicellular and microscopic in size. They may be motile or nonmotile.

(i) Many algae and fungi produce ciliated motile spores, called *zoospores*. They swim about in water with the help of cilia, settle down and develop into new individuals. In *Ulothrix* and *Chlamydomonas*, the protoplast of the parent cell divides to form 4-8 motile spores called *zoospores*. Under favourable conditions each zoospore develops into a new plant. In *Vaucheria*, the whole mass of protoplasm escapes from the mother cell as a single large multicilliate and multinucleate
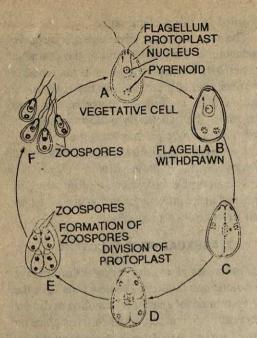
Fig. 10.13 A sexual reproduction in Chalamydomonas by zoospores.

Fig. 10.14 A sexual reproduction by spores in Rhizopus.

zoospore. It swims in water for a while, comes to rest and germinates into a new *Vaucheria* filament.

(ii) In terrestrial fungi like *Rhizopus* and *Mucor,* monciliate and nonmotile spores are produced within a sac-like structure, the *sporangium*. These on germination form new mycelium of the plant body.

(iii) True spores are borne by the sporophytic generation. Thus, the sporogonium (sporophyte) of moss plant reproduces asexually by spores. Similarly, ferns, *Lycopodium* and *Equisetum* bear pores and reproduce asexually by them. Since these plants bear only one kind of spores, these are known as *homosporous*. Flowering plants bear two kinds of spores - *microspores* and *megaspores*. Therefore, these plants are called *heterosporous*.

3. SEXUAL REPRODUCTION

This consists in the fusion of two sexual reproductive units, called *gametes*. These are microscopic, unicellular structures. To reproduce sexually two similar or dissimilar gametes fuse together and form a *zygote*. Zygote develops into a new plant.

Kinds of Sexual Reproduction

Depending upon the shape, size and structure of gametes, the sexual reproduction is of the following three types—

(i) **Isogamous**—This is a kind of sexual reproduction which involves the fusion of gametes that are similar in size, structure and appearance, *e.g. Chlamydomonas Spirogyra* and *Ulothrix.*

(ii) **Anisogamous**—This type of sexual reproduction involves the fusion of dissimilar gametes out of which one is smaller and more active while the other is larger and less active *e.g. Chlamydomonas brunii.*

(iii) **Oogamous**—In this kind of sexual reproduction, one of the fusing gametes is small and always motile and is called the *sperm* or *spermatozoid*. The other gamete is large and non-motile and is called the *ovum* or *egg*. Oogamy is considered to be an advanced type of sexual reproduction and is found in higher plants like Bryophytes, Pteridophytes, as well as

ISOGAMETES ANISOGAMETES SPERM ♂ OVUM ♂ GAMETE ♀ GAMETE

ISOGAMY ANISOGAMY OOGAMY
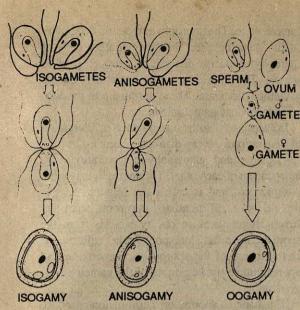
Fig. 10.15 Fusion of different types of gametes during sexual reproduction.

flowering plants.

Sex Organs—Not only gametes, but the sex organs in which these gametes are formed also show a distinct differentiation. In lower plants like *Chlamydomonas* and *Spirogyra* special sex organs are absent and the content of the cells are directly transformed into gametes. In higher plants highly specialized sex organs are formed. The male sex organs that develop on the gametophytes in Bryophytes and Pteridophytes are referred as *antheridia* and the female organs as *archegonia*. In antheridia are produced a large number of flagellated and motile sperms, whereas s single large, nonmotile egg is produced in archegonia.

Fertilization—To bring about fertilization, the male gametes or sperms in Bryophytes and Pteridophytes or entire male gametophytes or sperms in Gymnosperms and Angiosperms are liberated from the plant. These find their way to the female sex organs. In Bryophytes and Pteridophytes the sperm swim through the neck of archegonium and reach the egg located at the base. However, in seed-bearing plants (Gymnosperms and Angiosperms) the male gametes are enclosed in pollen grains and are carried by wind, water, insects and other animals to long distances before reaching the egg. On reaching the female sex organs, the pollen grains germinate and transport the male gametes to the egg.

Embryo—In the Thallophytes the zygote does not develop into an embryo but in other groups of plants (Bryophytes, Pteridophytes and Spermatophytes), the zygote after repeated divisions forms a distinct embryo. Again, in Bryophytes, Pteridophytes and Gymnosperms, nutrition for the development of the new sporophyte is provided by the gametophyte, but in flowering plants, a special tissue, the *endosperm*, formed as a result of fertilization, serves the function of nutrition to the developing sporophyte.

Seed—In the Bryophytes and Pteridophytes, the sporophyte developed from the zygote continues its growth to form the adult plant. In Gymnosperms and Angiosperms, the growth of the sporophyte stops temporarily after a certain period when the embryonic plant has been formed. The embryo remains enclosed in the surrounding tissues of the sporophyte which together constitute the seed. Seeds disperse the embryonic sporophyte to long distances and help them to establish in new localities.

Alternation of Generations

Sexually reproducing plants, in general, pass through two phases of development to complete their life cycle. These phases are- (i) the spore producing phase, the *sporophyte* or *sporophytic generation* or *diploid generation*, whose nucleus bears two chromosome complements (2n), and (ii) the gamete producing phase, the *gametophyte* or *gametophytic generation* or *haploid generation* having only one chromosome complement. These two phases or generations follow each other in regular sequence in the life-cycle of sexually reproducing plants. The phenomenon of alternation or diploid or saprophytic and haploid or gametophytic generations is known as *alternation of generations*.

The sporophytic generation is initiated by the fusion of two gametic nuclei. The two nuclei fuse to form a diploid nucleus having two chromosome complements (2n). Sooner or later, meiosis takes place whereby the chromosome number is reduced by half during the formation of spores. This marks the end of sporophytic generation and the beginning of the gametophytic generation. The spore is thus the first cell of the gametophyte. The gametophyte produces gametes, which on fusion,
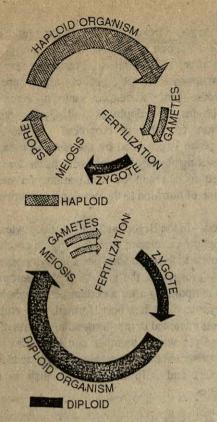
Fig. 10.16 Variation in the duration of sporophytic (diploid) and the gametophytic (haploid) generations in plants.

result in the formation of a new sporophyte. The advantages resulting from alternation of generations are—

The sporophyte and gametophyte generations differ in their relative conspicousness in structure and duration. Majority of algae like *Chlamydomonas* and *Spirogyra*, and fungi like *Rhizopus* have a conspicuous gametophyte and the sporophyte is relatively inconspicuous, short in duration, and more or less dependent for food upon the gametophyte. In these plants the diploid nucleus divides meiotically immediately after its formation. As such, there is alternation of an elaborate gametophytic generation and a very short single-celled diploid or sporophytic generation.

In *Bryophytes* the main plant body is a gametophyte. It bears gametes. Male gamates or sperms are produced in antheridia and female gametes or eggs are produced in archegonia. With the fusion of male and female gametes, the *sporophytic phase begins*. The zygote develops into a multicellular sporophyte, still borne on the gametophyte. The sporophyte remains dependent on the gametophyte. The spore mother cells of sporophyte undergo meiosis to produce haploid spores. The spores are the beginning of the gametophytic phase. These germinate to produce an independent gametophyte.

In *Pteridophytes*, the phenomenon of alternation of generations is very distinct. Though, both the sporophytic and gametophytic generations are independent of each other. The sporophyte is more conspicuous, and is called the fern plant. It is diploid and is differentiated into roots, stem and leaves. It produces spores by meiosis from the spore mother cells. Thus spore mother cells are the last structure of the sporophytic generation and spores initiate the beginning of the gametophytic generation.

The haploid spores, on germination, produce prothallus, which is the gametophyte. It reproduces sexually by the formation of gametes. Thus sperms and eggs are the last structures of the gametophyte. The diploid oospore formed as a result of the fusion of sperm and egg germinates into sporophyte the fern plant.

In Gymnosperms and Angiosperms also the sporophyte is the dominant phase in the life-cycle. The gametophyte is highly reduced and produces the gametes while still enclosed within the tissues of the sporophyte.

From the above account it is evident that in lower plants like Algae and certain Fungi, the gametophytic generation is dominant and more conspicuous and the sporophyte is reduced and inconspicuous. In Bryophytes also the gametophytic generation is well developed and conspicuous but the sporophytic generation also starts becoming conspicuous though still dependent upon the gametophyte. In Pteridophytes both the generations are independent but the sporophyte is more developed and forms the main plant body. In Gymnosperms and Angiosperms the sporophyte is the dominant generation whereas the gametophytic generation is greatly reduced and inconspicuous.

SPECIAL MODES OF REPRODUCTION

1. Apomixis

Apomixis is the irregular mode of reproduction resulting in the development of an embryo without the act of fertilization. It may be (a) apogamy,

(b) adventive embryony, (c) parthenogenesis, (d) diplospory and (e) apospory.

(a) Apogamy—It is the development of an embryo from any cell of the gametophyte (prothallus) other than the egg cell. The embryo so formed grows into the sporophyte.

(b) Adventive embryony—When the embryo develops directly from the cells of nucellus or the integuments, it is said to be *adventive embryony*. In adventive embryony, the embryo formed by syngamy or the fusion of gametes degenerates or competes with the adventive embryo.

Adventive embryony usually results in the formation of more than one embryo per seed. In certain species of *Citrus*, there may be 2-40 embryos per seed, but only one will be the zygotic or sexual embryo.

(c) Parthenogenesis—It is the development of zygote from the egg-cell without the act of fertilization. It is seen in many lower plants, *e.g. Spirogyra, Mucor*, certain ferns. In certain species of *Compositae* and *Solanaceae*, the embryo may develop without fertilization. This process of development of embryo from the diploid unfertilized egg without the act of fertilization is known as *parthenogenesis*. For parthenogenesis, the stimulus of pollination is essential. When the embryo develops from a haploid egg cell, the germination is more or less normal but the plant becomes small and sterile.

Sometimes the ovary develops normally into a fruit without fertilization. This type of fruit development is called *parthenocarpy*. Natural parthenocarpy is found in many plants, *e.g.* banana, apple, grapes, pear, papaya, guava etc.

(d) Diplospory—In this case diploid embryo sac is formed without meiosis from the megaspore mother cells. Diplospory is of common occurrence in *Areva tomentosa*.

(e) Apospory—When the diploid embryo sac develops from any other cell of the nucellus, it is known as *apospory* as in orange, mango, prickly pear etc. Apospory is also seen in certain ferns and mosses. In these plants gametophyte developing by this method is diploid and bears both antheridia and archegonia.

2. Polyembryony—Occurrence of more than one embryo in the seed is known as *polyembryony*. Many species of dicotyledons and monocotyledons exhibit this phenomenon. Polyembrynoy is common among conifers. Embryos may be formed in the seed in the following ways—

(i) There may be more than one egg-cell in the embryo sac or more than one embryo sac in the ovule, and all the egg cells may be fertilized.

(ii) A number of embryos may develop simultaneously from different parts of the ovule.

Polyembryony is commonly found in conifers where there are many archegonia in the ovule.

Questions

1. Write an account of various methods of vegetative reproduction in flowering plants.
2. What are the advantages of propagating the plants by vegetative means ?
3. What are the methods of asexual reproduction found in unicellular and multicellular plants? Add a brief explanatory note on each of them.
4. How does vegetative reproduction differ from agamospermy? Enumerate various types of vegetative reproduction.
4. Write short notes on the following :
   (a) Adventive embryony,   (b) Parthenogenecis,   (c) Layering,   (d) Micropropagation.
5. What is agamospory ? Explain.
6. Enumerate the merits and demerits of vegetative propagation in plants.
7. Seeds of many citrus species contain more than are embryo. What are such seeds called? How are the additional embryos formed ?
8. If you are asked to multiply a selected variety of seedless fruit plant, what procedures would you adopt ?
9. If a branch of dasehri mango is grafted on a tree producing desi mangoes, what type of mangoes will be borne on the grafted branch and other branches of the plant ?
10. Explain in breif apomixis.
11. What is the name of the seed containing many embryos.
12. State whether the following statements are correct or wrong :
    (a) *Bryophyllum* is propagated with the help of leaf cuttings.
    (b) The process of development of embryo from the diploid unfertilized egg without the act of Fertilization is known as parthenogenesis.
    (c) During fertilization the happloid male and female gametes reconstitute the sporophytic diploid generation.
13. What is sexual reproduction ? Mention different types of sexual reproduction.

Sexual Reproduction in Lower Plants

Green algae were the first plants to discover sex. A very primitive form of sexual reproduction is the combination of genetic inheritance from two parents. It can be seen in *Chlauydomonas* and *Spirogyra.*

Chlamydomonas throws considerable light on the origin and differentiation of sex. The zoospores and gametes are remarkably similar to one another in all respects except that of size. The method of their formation and their mode of liberation are also similar. If the division stops early, zoospores are formed and when continues, for a longer period, gametes are formed. The zoospores develop into independent individuals, whereas gametes can develop into new individuals only after sexual fusion. This is the first step towards the establishment of sexual process in the plant kingdom. Normally all stages of sexual process in the plant kingdom. Normally all stages of sexual reproduction from primitive isogamy to oogamy are found in this genus.

A variant of primitive type of conjugation can be seen in another green alga, the *Spirogyra.* It is found in the form of long multicellular filaments. Certain of the haploid filaments can produce gametes, and the cells of one filament can then fuse with those of another in a process called conjugation.

SPIROGYRA

Spirogyra is a free-floating filamentous alga

CELL WALL

CHLOROPLAST

PYRENOID

NUCLEUS

CYTOPLASMIC STRAND

UNBRANCHED FILAMENT

A   B   C
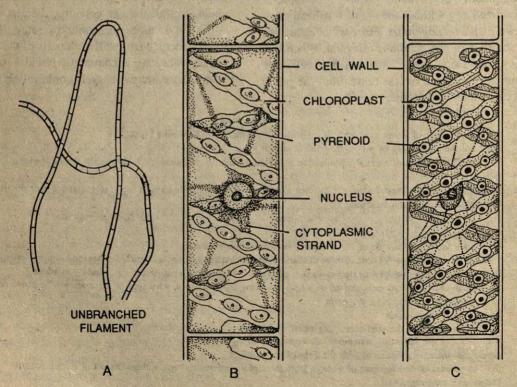
Fig. 11.1 Spirogyra—A. Unbrached Filaments; B+C. Cells of Spirogyra.

found abundantly in ponds, pools, ditches, springs and slow running streams etc. and forms the scum or silk over the water surface. Hence, it is commonly known as *pond scum* or water silk.

The plant body is multicellular unbranched filament consisting of a single row of cylindrical cells. The cells are identical and are not differentiated into basal or apical cells.

The cell wall is formed of cellulose and pectin. The pectin when dissolved in water forms a slimy or mucilaginous sheath and gives to the filament a slippery-touch.

Within the cell wall, the protoplasm contains a large central vacuole, a nucleus and the *chloroplasts.* The nucleus is centrally placed and is held in position by cytoplasmic strands which join the parietal layer of cytoplasm. The *chloroplasts* are a number of spirally twisted band-shaped structures with smooth, wavy or serrated margins. Each chloroplast has several pyrenoids placed at regulr intervals. These are centres of starch formation.

SEXUAL REPRODUCTION

It is isogamous (fusion of two nonmotile gametes) and may be of the following types:

1. Scalariform conjugation—It is the common method of sexual reproduction in *Spirogyra*. Two filaments come to lie in contact side by side and form small dome-shaped protuberances in their longitudinal walls facing each other. These tubular outgrowths are known as conjugation tubes and the two filaments assume a ladder-like appearance. With the elongation of the conjugation tubes, the filaments are pushed apart and the end walls in between the conjugation tubes dissolve forming passages from the cells of one filament to the other. These passages are called the *conjugation tubes.* By losing water and receding from the cell-wall, the contents of the cell of one filament contract to form the naked, non-motile and non-ciliated *male gamete.* The male gamete squeezes itself through the conjugation tube into the cell of the opposite filament, the female gametangium. Now the contents of the female gametangium begin to contract and form a rounded, naked and non-motile *female gamete.* The two gametes, otherwise, are morophologically alike and called the *isogametes.* In fusion, the chloroplasts do not take any part and only the protoplasts with their nuclei fuse to form a spherical zygospore.

2. Lateral conjugation—In some species of *Spirogyra*, conjugation takes place between the adjacent cells of the same filament. It starts with the formation of a passage between the two adjacent cells either by conjugation tube formed near the ends of the two adjoining cells or through an opening in the walls of the two cells. Now, the contents of one cell migrate into the other and fuse with its contents to form a zygospore.

3. Direct lateral conjugation—In *S. jogensis* no conjugation tube is formed but instead, the male gamete fuses with the female gamete in the adjoining cell by directly perforating the separating septum. This is called *direct lateral canjugation.*

Sometimes, the gametes fail to conjugate. They become thick-walled and behaving like ordinary zygospores develop into new filaments. Such asexual zygospores are known as azygospores or parthenospores

Zygospore—Each zygospore is circular, cylindrical or ellipsoidal. It is dark brown in colour and has a thick wall consisting of three layers. The outer layer is known as *exposre*, the middle as mesospore and the inner one as endospore. The inner and outer walls are made up of cellulose and middle of chitin. Zygospore contains oil as reserve food material.

Germination of zygospore—The zygospore sinks to the bottom of the pond due to the decay of the walls of the female gametangium. There, it lies dormant and sruvives long periods of drought. On the return of favourable conditions, it germinates. The diploid zygote nucleus undergoes reduction division forming four haploid nuclei. Three of them disintegrate leaving only one functional nucleus. After these changes, zygospore absorbs water, the outer two layers rupture and the inner wall grows out into a small germ tube. It divides by a

transverse wall to form a two-celled *germling*. The upper cell turns green and by repeated divisions forms a green cellular filament. The lower or basal cell is colourless and functions as a rhizoidal cell. Soon the basal cell disintegrates and the filament is detached and floats in water.

Alternation of Generations

The main plant of *Spirogyra* is haploid and a gametophyte. It is independent and reproduces sexually by the formation of gametes. The gametes fuse together to form zygospore which is diploid and constitute the sporophyte. It undergoes meiosis
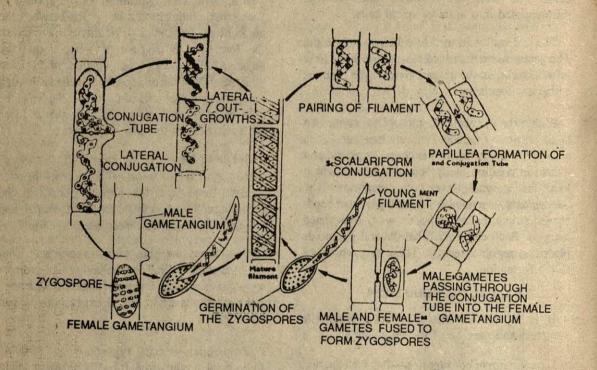
Fig. 11.2 Life-history of Spirogyra.
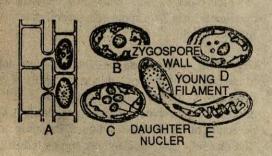
Fig. 11.3 Spirogyra A. Zoospore liberated from the filament; B. Meiotic division in zygospore to give four haploid nuclei; C. three of the four nuclei degenerate; D. Germinating zygospore.

before germination. The filament arising from the zygospore is haploid and represents the gametophytic generation. Thus, in *Spirogyra*, the gametophyte is more conspicuous and dominant, whereas the sporophyte is inconspicuous and short-lived.

Differentiation of Sex in Spirogyra

The active gamete in *Spirogyra* may be considered as *male* and the passive one as *female*, though they do not show any morphological differences, and for all purposes are male gametes. Thus, *Spirogyra* represents a case of physiological heterogamy. In some species of *Spirogyra*, all the male gametes are produced in the cells of one

filament and the female gametes in the other. Such filaments are termed as *heterothallic*. In other species some cells function as males and other as females. These filaments are termed as *homothallic*.

Final step in the evolution of sex is the development of specialized cells to produce the gametes rather than having them produced by just any cell in the body. This last step is seen in *Volvox*, a colonial form that may contain as many as 40,000 cells in a single sphere. Some of these cells specialize to form an *antheridium* or sperm producing structure, while others form an *oogonium.*

Some colonies may contain both antheridia and oogonia, but others contain only one type of gamete-producing structure and may thus be said to be either male or female plants. An interesting feature of *Volvox* is that if an egg is not fertilized, it may undergo mitotic divisions and produce a new colony all by itself.

The alternation of diploid (asexual) and haploid (sexual) generations is a characteristic of multicellular plants.

In the life-cycle of the sea-lettuce *Ulva lactuca*, the diploid sporophyte of this sea-shore alga is a two cell thick leaf. The specialized cells (the sporocytes) differentiate and then undergo meiosis, producing haploid spores. The four flagellated spores swim and then settle down and lose their flagella. They divide mitotically producing a two-cell thick filament. This haploid gametophyte is indistinguishable from the sporophyte. A given gametophyte produces only male or female gametes. Gametes arise mitotically within single celled *gametangia*. Male gametes are smaller and female gamete is larger. So, *Ulva* is anisogamous. Male and female gametes form *zygote*. After resting for a while, zygote divides mitotically forming a new sporophyte. Any gamete that fail to fuse, settle down and form zoospores. The zoospores divide mitotically to form new gametophytes.

Thus in the life cycle of Ulva, both *gametophyte* (haploid) and *sporophyte* (diploid) *generations* are multicellular and morphologically identical. Such a life cycle is called *isomorphic.*
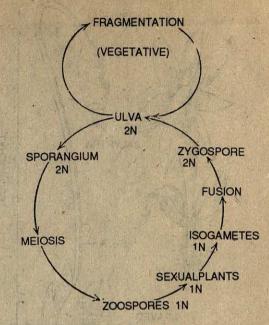
Fig. 11.4 Life cycle of Ulva.

MOSSES AND FERNS

In the two major lines of land plants, non-vascular and vascular plants, two distinct patterns were established. In non-vascular plants, the gametophyte generation predominates, for example, in mosses, the gametophyte is prominent, long lived, leafy generation. In all vascular plants, the sporophyte generation with its wots, stem and leaves predominates.

Both in mosses and vascular plants, there is progressively more protection for the developing gametes, a gradual escape from water based fertilization and increased protection for the embryonic sporophyte.

A MOSS : FUNARIA

The life cycles of mosses and liverworts involve alternation of well developed gametophyte and sporophyte generations. Mosses form a soft green velvet over damp walls, shady moist places and on the trunks of the trees during the rainy season. Moss plants are usually small and 2 cm. in height.

Plant body consists of a slender, erect stem bearing leaves towards the apex of the stem. The basal portion bears numerous rhizoids which attach

Fig. 11.5 A moss plant with sporophyte.

Labels in figure: CAPSULE, CALYPTRA, SETA, LEAVES, RHIZOIDS, SPOROPHYTE, GAMETOPHYTE

Each antheridium is an orange-coloured club-shaped body with a short multicellular stalk. The antheridium body is surrounded by a single-layered wall or jacket. Within it is dense mass of small cubical cells known as *androcytes* or *spermatocytes*. Each androcyte produces a single, haploid and biciliated sperm.

Archegonia—Their clusters are found at the apex of the female shoot which arises as a lateral branch from the base of the male shoot. Archegonia are interspersed with paraphyses and surounded by green vegatative leaves, called *perichaetial leaves*.

Each archegonial cluster with its surrounding leaves is called *perichaetium*. Archegonium is a flask-shaped body with a swollen basal *venter* and an elongated narrow *neck*. The neck is enclosed by a single-layered jacket formed by six vertical rows of neck-cells. The venter contains a naked female gamete, the *oosphere* or *egg cell* and a *ventral canal cell*. The canal contains a number of small *canal cells*.

Fertilization

It takes place in the presence of water *i.e.* when the plants are wet due to rain or dew. In a mature archegonium all the neck cells degenerate into mucilage containing cane-sugar and provide a clear passage in the neck-canal.

At maturity, the antheridium bursts at the apex and the spermatozoids are liberated in a mass of mucilage. The mucilage dissolves in water and the antherozoids are set free. They swim in water and are attracted towards the archegonium by *chemotactic* response. A number of them enter the neck of archegonium but only one fuses with the egg and forms the *zygote* or *oospore*.

With the formation of oospore of zygote, gametophytic phase ends and the sporophytic generation starts. The oospore undergoes repeated divisions and develops into a sporogonium. This represents the sporophyte plant.

Structure of the Sporogonium

The sporogonium of moss is differentiated into the following three regions :

(a) **Foot**—It is the basal portion of the sporogonium that lies embedded in the parent tissue and absorbs water and nutrition from it.

(b) **Seta**—It is a slender and stalk-like structure

the moss plant to the soil and help in absorbing water and minerals from the soil.

Structure of the Sporogonium

The moss plant is a gemetophyte and bears the sexual or reproductive organs. The male and female reproductive organs *i.e.* the antheridia and archegonia are borne at the tips of erect leafy branches in clusters on the same plant but on different branches. *Funaria* is thus *monoecious*.

Antheridia—These are found in clusters at the apex of the male branches and are surrounded by leaf rosette. These are called *perichaetial* or *perigonium cups*. The antheridia are intermixed with multicellular hair-like structures called the *paraphyses* which help in protection, water conservation, photosynthesis and building up pressure for efficient sperm discharge.

Fig. 11.6 Funaria—A-Moss plants B. V.S. through apex of a moss plant.

Fig. 11.7 C. A bursting antheridium with antherozoids; D. Biciliated antherozoid.
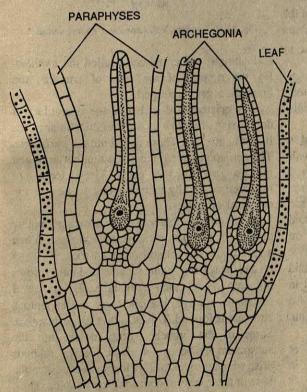
Fig. 11.8 Funaria. V.S. female shoot showing archegonia and paraphyses.
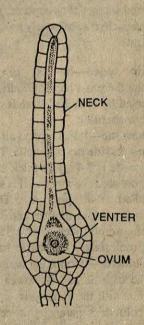
Fig. 11.9 Funaria—An archagonium.

between the capsule and foot. It helps in the conduction of absorbed water and food to the capsule.

(c) **Capsule**—The capsule is a pear-shaped body. At the apex, it is covered by a cup-like structure, the *calyptra*, which soon falls off. The capsule is mainly concerned in the production of spores and their efficient dispersal. The capsule of moss consists of three parts, *i.e.* (1) the *apophysis*, (2) *theca*, and (3) *operculum* or *lid*.

(1) **Apophysis**—This is the basal portion of the capsule which remains attached with seta. It consists of a solid mass of cells, the epidermis which contains stomata. Beneath the epidermis there is a spongy zone of parenchyma cells containing chloroplasts. These constitute the food-making tissue of the sporogonium. For water and minerals, it depends upon the gametophyte and thus is *semiparasite*.

(2) **Theca**—This forms the middle and fertile region of the capsule and comprises of the following structures :

(i) **Capsule wall**—It is made up of epidermis, hypodermis and spongy parenchyma. The epidermis is single-layered and hypodermis is two-layered without choloroplasts. The cells of the spongy parenchyma are loosely packed and contain chloroplasts.

(ii) **Air space**—Internal to the spongy parenchyma there is a large cylindrical *air-space*. It is traversed by branched strands of green cells called the *trabeculae*.

(iii) **Spore sac**—It lies next to air cavity and is situated just outside the columella. The outer wall of the spore sac is 3-4 layers thick and is referred as outer spore sac. The inner wall is single-layered and is called *inner spore sac*. The spore sac contains many spore mother cells with diploid number of chromosomes. Each of these later on divides by meiosis to produce four haploid spores.

(iv) **Columella**—It forms the sterile central solid core of the capsule and its lower portion is in continuation with the apophysis. It consists of a mass of colourless parenchyma cells with thin walls.

(3) **Operculum**—It is a cap-like lid and lies at the tip of the capsule. It is 4-5 cell layers in thickness. It protects the peristome and is associated with the following structures :

(i) **Annulus**—At the base of the operculum and above the rim of the capsule is a ring of
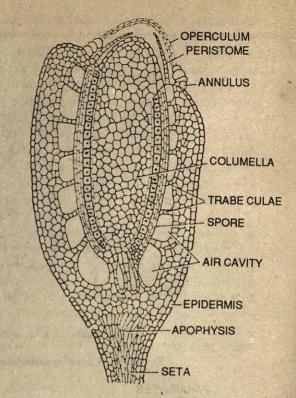
Fig. 11.10 Funaria. V.S. capsule of sporogonium.

cuticularised epidermal cells called the *annulus*. By the rupture of the cells of annulus, the operculum gets separated.

(ii) **Peristome**—Just below the operculum, a double ring of yellow, pointed multicellular teeth-like structures lie. These constitute the *peristome*. The peristomial teeth are 32 in number arranged in two rows of 16 each. These teeth are hygroscopic and by their movements help in the dispersal of spores.

Germination of spores—The spores germinate only in the presence of moisture and light. When a spore falls on wet soil or moist rock, it swells up and the softened exine ruptures and intine grows out into a delicate germ tube. By repeated divisions, a much branched green filamentous structure is formed. This is known as *protonema*. Some of the branches grow down into the substratum and become rhizoids. Soon lateral buds arise which grow into erect leafy shoots. From the base of these leafy shoots arise the rhizoids. Thus, protonema forms a purely vegetative and short-lived phase in the life-cycle of moss.

Mechanism of dispersal of spores—After the
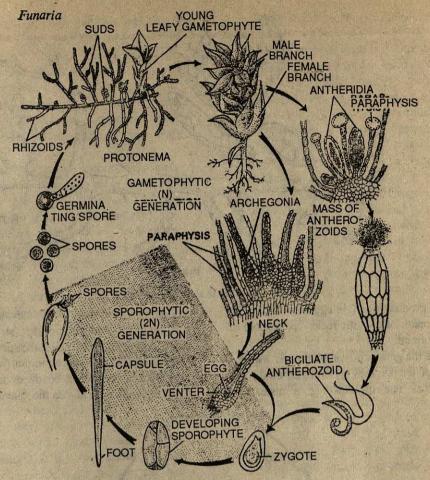
Fig. 11.11 Life-history of Funaria.

ripening of spores capsule starts drying up. This is followed by the shrinking of the annulus cells which subsequently rupture. In the meantime thin-walled tissues in the capsule as well as columella dry up and degenerate,thus leaving a central cavity. This cavity is filled with the powdery mass of the spores. By this time the lid or operculum falls off, thus exposing the peristomial teeth. These teeth are highly hygroscopic. When the humidity is high they bend inwards and straighten up when it is low. By these movements, they lift out spores which are carried away by the wind and dispersed. The seta also helps in the dispersal of spores. It being slender and hygroscopic, swings and thus aids in the efforts of the peristome in dispersal of spores.

Alternation of Generations

The life-cycle of moss plant has two distinct phases or generations. The life-cycle is complete only when plant passes through both the stages, *i.e.* gametophyte and the sporophyte generations. The gemetophyte reproduces sexually by means of gametes. The fusion of gamets results in the formation of sporophyte. The sporophyte reproduces asexually by the formation of spores. These spores give rise to the gametophyte.

The moss plant is a gametophyte and develops from the protonema. The plant consists of an axial stem with leafy shoots and rhizoids. The leafy shoots bear at their tips the sex organs, *i.e.*, antherozoids and archegonia. The antheridia produce male gametes or antherozoids and the
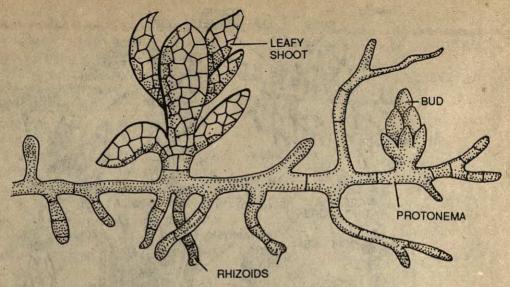
Fig. 11.12 Protonema of moss

archegonia produce a single **egg** or **oosphere** in each. As a result of gametic fusion an oospore or zygote is formed.

This ends the gametophytic phase and with the formation of the zygote, sporophytic or diploid phase begins. The diploid zygote instead of producing a moss plant develops into a complicated and elaborate structure, the sporogonium . It is also called the **sporophyte**. The sporophyte or the sporogonium is capable to assimilate carbohydrates but depends for its water supply and the minerals on the gametophyte. It is,
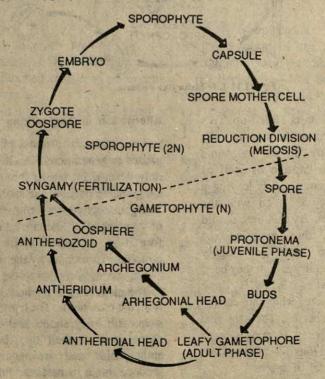
Fig. 11.13 Life-cycle of Funaria.

therefore, semi-parasite on gametophyte and is differentiated into **foot, seta** and **capsule.** In the capsule of sporogonium, as a result of **reduction division** or meiosis, are produced haploid spores. This is the beginning of the gametophytic or haploid phase. Each spore on germination instead of forming a sporogonium develops into a haploid protonema which gives rise to the leafy gametophyte.

It is evident from the above account that the two generations alternate with each other. One is the gametophyte generation and is haploid. The other one is the sporophyte generation and is diploid. The haploid gametophyte consists of all the structures starting from the spore upto the gametes, *i.e.* the spores, protonema, leafy shoot, antheridia and archegonia, antherozoids and egg-cell or oospore. On the other hand, structures that belong to the diploid sporophyte are the oospore or zygote, sporogonium and spore mother cells.

Of the two generations, gametophyte is of longer duration and sporophyte is short-lived. The gametophyte is more conspicuous and forms the main generation. It is directly attached to the substratum from where it absorbs water and mineral salts. Further, it has an assimilatory tissue, the cells of which contain chloroplasts. All these make the gametophyte a complete independent individual which absorbs water and minerals and manufactures its also capable of reproducing vegetatively.

The sporophyte on the other hand is less conspicuous and is not capable of leading an independent life. It is also not capable of vegetative propagation. Though the sporophyte is able to assimilate its own food but it depends for its water and mineral requirements on the gametophyte. It is, therefore, a semi-parasite.

From the above account it is clear that the main event in the life-cycle of moss is the supremacy of the gametophyte over the sporophyte.

Salient Features

1. The spores on germination form green, branched and filamentous protonema.
2. The gametophyte comprises of two distinct stages, the **juvenile** stage represented by the *protonema* and the *adult stage* represented by the so called *leafy moss plant.*

3. The leafy moss plant is differentiated into the stem bearing the **leaves** in its upper part and multicellulr, branched rhizoids with oblique septa arising from its basal part.
4. The leafy plant bears **antheridia** and **archegonia** in terminal clusters.
5. The antheridia are borne on the main shoot and archegonia on a lateral branch.
6. Biciliate sperms produced in antheridia swim to the neck of archegonia.
7. The diploid oospore formed by the fusion of sperm with egg is retained within the venter and it germinates in situ.
8. The oospore by repeated **mitotic divisions** forms the **embryo sporophyte.** It is parasitic upon the gametophyte.
9. The embryo develops into the mature **sporophyte** or **sporogonium** which is differentiated into **foot, seta** and **capsule.**
10. The capsule is differentiated into the green apophysis, theca and operculum.
11. The hygroscopic teeth constituting the peristome assists in the dispersal of spores.
12. The spores on getting suitable environment germinate to form protonema.
13. The upright leafy moss plants arise as lateral buds on the protonema.

A FERN—DRYOPTERIS

Dryopteris is a fern which belongs to class Filicineae, the largest class of living Pteridophytes. The pteridophytes constitute the third great division of the plant kindgom. These are vascular plants which do not produce seeds. For this reason they are called the primitive vascular plants. They share the following characteristics with the bryophytes-

1. They are terrestrial in habit.
2. Sex organs multicellular each with a jacket layer of sterile cells.
3. The male gametes are ciliated.
4. Need of water at the time of fertilisation.
5. Retention of the fertilised egg within the venter and its early development within it.
6. Formation of embryo.
7. The fertilized egg is retained within the venter of the archegonium and develops into the embryo.

8. Constant occurrence of heterologous type of alternation of generations.

In spite of the above mentioned resemblances, the pteridophytes show a great advance over the bryphytes in the following respects—

1. Independent sporophyte which is differentiated into roots, stems and leaves.
2. Development of vascular tissues, the xylem and phloem, in the vegetative organs.

In the bryophytes the gametophyte is green and independent *i.e.* it manufactures its own food. It constitutes the dominant phase in the life cycle. The sporophyte is small and leafless. It is dependent for its nutrition wholly or partly on the gametophyte.

In the pteridophytes the condition is reversed as the gametophyte is small and inconspicuous. The sporophyte, on the other hand is well developed and completely independent. It is the dominant plant and is differentiated into roots, stem and leaves with well-developed vascular tissue.

External Characters

Drypteris which is commonly known as shield fern is taken as an example. The plant body is a diploid sporophyte, *i.e.* it reproduces by spores. It is differentiated into **stem, root** and **leaf.** The stem is a rhizome and measures about eight inches. It grows obliquely upwards through the soil but a little above the surface of the ground. The rhizome is covered with the persistent bases of the dead leaves. The stem does not bear aerial shoots and is usually unbranched. Each season a cluster of a few large green leaves come out into the air.

The roots are adventitious. These arise as small, wiry structures from the lower surface of the
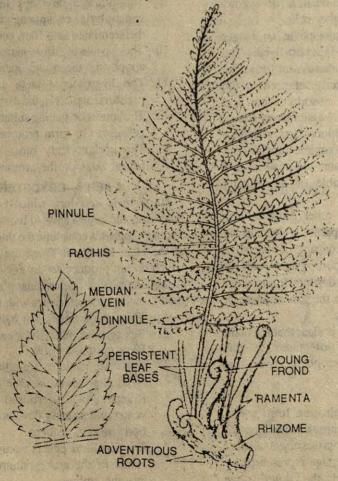
Fig. 11.13 **A fern plant showing rhizome, stem and leaves. Right Portion of pinna with sori.**

new plants. The younger parts of the rhizome, petiole and lamina of the leaf are covered by the clusters of brown hair-like structures the *ramenta*. The ramenta are protective in function.

The leafy fern plant is a *sporophyte*, *i.e.* it bears spores and reproduces asexually. The fern plant is *homosporous* as it produces only one kind of spores. These spores are known as *meiospores*. The spores are produced in spore sacs known as *sporangia*. The sporangia are dark brown structures. These are aggregated in groups called *sori* and develop on the under surface of the leaf.

(i) **Sori**—The sori occur in two rows on the leaflets or *pinnules* as in the higher plants. The stomata are confined only to the lower surface. The *mesophyll* is not differentiated into palisade and rhizome and fix it to the substratum. The primary root is short-lived.

The leaves are large and arise from the upper surface of the rhizome. Though the leaves are a few in number, they form the most conspicuous portion of the plant. The leaves are petiolate and pinnately compound.

The young leaves have *circinate ptyxis*, i.e. they are rolled from the apex downwards. The venation is furcate, the leaflets or *pinnae* are arranged in two lateral rows on the rachis. The pinnae, in their turn, have deep and complete incisions to form numerous independent segments called the *pinnules*. The leaves do not have axillary buds and stipules but adventitious buds develop on the bases of old leaves. These on separating develop into spongy parenchyma. The cells contain chloroplasts and have intercellular spaces. The veins traversing the mesophyll have *collateral* vascular tissues and that of leaflet *concentric* vascular tissues.

Sporangia and Spores

The fern plant is a *sporophyte i.e.* it bears spores and reproduces *asexually*. The spores are produced in spore sacs known as *sporangia*. The sporangia are dark brown structures. These are aggregated in groups called *sori* and develop on the under surface of the leaf. The sori occur in two rows on the leaflets or *pinnules* arranged in one row on either side of the mid-rib. Each sorus is protected by a thin membranous kidney-shaped covering called the *indusium*. The leaves that bear the sori are known as *sporophylls* and those without sori as *tropophylls*.

(ii) **Sporangium**—Each sporangium consists of a long slender multicellular stalk and dark brown biconvex *capsule*. The capsule wall is made up of a single layer of thin and sterile cells. The capsule wall has a vertical band or ring of specially thickened and cutinized cells running round its margin. This is known as *annulus*. The annulus has an unthickened portion made up of thin-walled, flat, narrow cells called *stomium*. The mature sporangium dehisces normally under dry conditions at the stomium. The annulus bends back and then suddenly returns to its original position thus ejecting out spores.

Fig. 11.14 (A) A fertile pinnule of Dryopteris (B) A fertile pinna of Pteris.
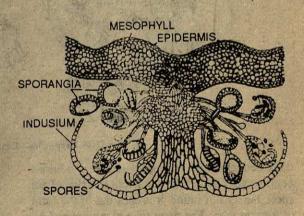
Fig. 11.15 Dryopteris—Section through a sorus.

(iii) Sporogenesis—Towards maturity the spore mother cells separate from each other and become spherical to form spores. Each mother cell has a diploid nucleus. The process of the differentiation of spores from the spore mother cells is called *sporogenesis*. During sporogenesis the diploid nucleus of each mother cell undergoes meiosis forming four haploid nuclei. Thus a tetrad of cells is formed. The cells of the tetrad separate and their walls thicken to form *meiospores* or *spores*.

(iv) Dehiscence of sporangium—The sporangia dehisce in the dry weather. The annulus and stomium take part in the dehiscence of the sporangium. When the mature sporangium dries, the outer thin walls of the annulus cells shrink move than the thickened walls. The annulus along with a portion of the capsule wall slowly bends backward, thus exposing and scattering the dusty dry spores with some force. Now the annulus and the capsule wall flip forward with a jerk scattering out the remaining spores into the air.

Spores—The spores are minute somewhat triangular in shape and brown or dark brown in colour. Each spore consists of a uninucleate protoplast surrounded by a thick, dark and rugged wall. It is two layered, the outer rough, hard and thickened *exine*, and the inner thin layer, the *intine*.

Germination of spores—The haploid spores are the beginning of the gametophytic generation. The

cells which by further divisions forms the *gametophyte* called *prothallus*.
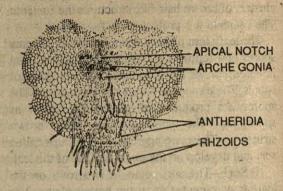
Fig. 11.17 Fern—Detailed structure of a prothallus showing position of archegonia, antheridia and rhizoids.

Prothallus—The mature prothallus is thallus-like heart-shaped structure. It consists of a thin flat mass of parenchyma cells containing numerous chloroplasts. The prothallus varies in size from $1/4$ inch to $1/2$ inch. It is only one-cell thick at the margin but many-cell thick at the notch. It bears numerous unicellular and brownish rhizoids on the lower side which attach the prothallus to the soil and absorb water and mineral salts. The prothallus is monoecious and bears the sexual reproductive organs, the *archegoina* and *antheridia* on the ventral surface.
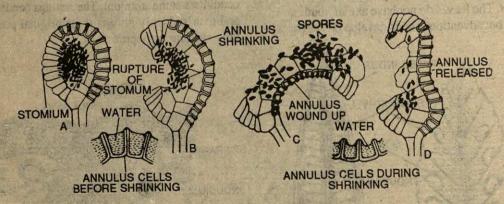
Fig. 11.16 Drypteries—Dehiscence of sporangium.

dispersed spores on getting favourable conditions begin to germinate. The outer wall or exine of the spore bursts and intine protrudes out in the form of a germ tube. The germ tube elongates and by repeated divisions forms a short green filament of

Sexual Reproduction

It takes place by the fusion of sperm with the oosphere or egg. The sperms are formed within the antheridia and a single oosphere or egg is formed in each archegonium.
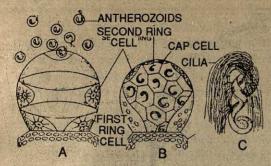
Fig. 11.18 Fern—Antheridium A. At dehiscence B. young antheridium. C. an antherozoid.

Antheridia—These are the male sex organs and develop on the ventral surface of the prothallus. They are found among the rhizoids near the apex away from the notch. These are slightly projected, small, spherical and sessile structures. Each antheridium is bounded by a wall consisting of only three cells—two annular ring cells and a single lid cell. Inside the antheridium there is a small number of *spore mother cells* or *spermatocytes*. Each spermatocyte produces a single, large, coiled, multiciliate *spermatozoid*.

Archegonia—These are female sex organs and develop in clusters near the notch on the ventral side. Each *archegonium* is a flask-shaped structure and consists of a basal swollen portion the *venter* and a short projecting slender neck. The venter lies embedded in the tissue of prothallus. It contains

Fig. 11.19 Fern—Different stages in the development of embryo.
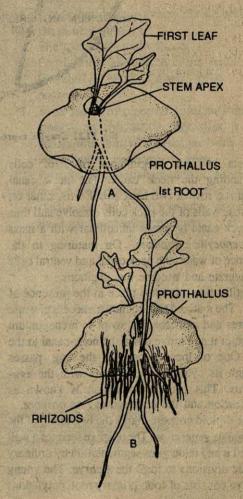
Fig. 11.20 Fern—Young sporophyte on a prothallus. A. Upper surface, B. Lower surface.

the naked *egg cell* and the *ventral canal cell* but no jacket wall. The neck is obliquely curved and
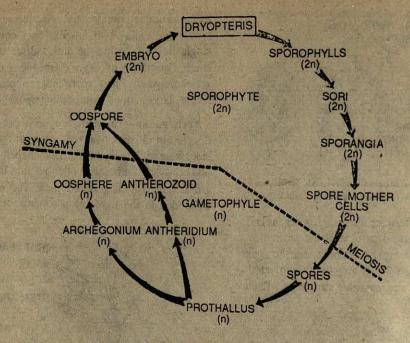
Fig. 11.21 Graphic representation of life cycle of Fern.

consists of four longitudinal rows of cells surrounding the neck canal. The neck canal contains a row of two *neck canal cells*. Later on the cross walls of the neck cells dissolve and thus the neck canal becomes unicellular with a mass of *coenocytic cytoplasm*. On maturing in the presence of water, the neck canal and ventral cells disintegrate and become mucilaginous.

Fertilization—It takes place in the presence of water. The matured antheridium on access of water ruptures and antherozoids swim to archegonium and enter it and move down the neck-canal to the egg. One of these penetrates the egg, passes through its cytoplasm and fuses with the *egg-nucleus*. This process of fusion is known as *fertilization* and the fertilised egg as *oospore*.

The diploid oospore marks the beginning of the *sporophyte generation*. The oospore secretes a wall around it and undergoes segmentation by ordinary mitotic divisions to form the *embryo*. The young embryo consists of foot, primary root, cotyledons and the stem axis.

The foot remains in close contact with the prothallus and acts as the suctorial organ for the absorption of food for the young sporophyte. As growth continues root and leaf of the embryo

emerge from the archegonial wall. Soon the primary root penetrates in the soil and the first leaf expands in light and air. With the development of root and leaf, the young sporophyte manufactures its own carbohydrate food, absorbs water and minerals from the soil, and starts leading the independent life. In the course of time primary root is replaced by the adventitious roots and the young fern plant becomes the parent sporophyte.

Alternation of Generations

The lie-cycle of fern consists of two phases *i.e.* *sporophyte* and the *gametophyte*. though both of these are independent vegetative individuals, they differ from each other in form, size, appearance, function and constitution. Of these two, sporophyte is more conspicuous, and is called the fern plant. The sporophyte or the fern plant is diploid and is differentiated into roots, stem and leaves. It bears spores and reproduces asexually. All the diploid structures *i.e.* oospore, embryo, the fern plant and the spore mother cells represent the sporophyte generation.

The formation of spores from the spore mother cell involves the *meiosis* or reduction division. Thus, spore mother cells are the last structures of

the sporophyte generation and the spores initiate the beginning of the gametophyte generation.

The haploid spores, on germination, produce an alternative individual called the *prothallus*. Prothallus is the second individual in the life-cycle and leads an independent life. This is known as gametophyte and reproduces sexually by the formation of gametes. The male and female gametes are produced in antheridia and archegonia respectively. The male gamete fuses with the female gamete or the egg to form diploid oospore or zygote. Thus, the sperms and the eggs are the last structures of the gametophyte. The gametophyte comprises haploid spores, prothallus, sex organs, and the male and female gametes. The diploid oospore on germination produces the sporophyte or the fern plant.

Thus, the two generations alternate with each other and the phenomenon is known as *alternation of generations*.

Salient Features

1. The fern plant is a sporophyte differentiated into a subterranean rhizome, roots and leaves.

2. The underground stem grows obliquely and is covered with persistent leaf bases.

3. The leaves are large and compound. The young leaves in bud condition have circinate ptyxis. The venation is furcate.

4. The sporangia containing spores occur in clusters called the sori. The sori are protected by indusium.

5. The spores are of one kind, and thus the ferns are homosporous.

6. The haploid spores germinate to give rise a small, independent gametophyte, the prothallus.

7. The thallus in heart-shaped and is attached to the soil by unicellular rhizoids. It is green and independent.

8. The antheridia and archegonia are borne by the same prothallus.

9. The sperms are multicilated.

10. Fertilisation takes place in the venter. The fertilized eg secretes a wall to become an oospore.

11. The oospore by repeated divisions forms an embryo attached to the prothallus. It soon grows into a new sporophyte with roots, leaves and an underground stem.

12. Fern plant exhibits alternation of generations with a well developed and dminant sporophytic generation and a reduced and short-lived gametophytic generation.

QUESTIONS

1. Describe sexual reproduction in *Spirogyra*.
2. Where does meiosis takes place in *Spirogyra*. Describe the germination of zygospore in *Spirogyra*.
3. Describe alternation of generations in *Spirogyra*.
4. Discuss differentiation of sex in *spirogyra*.
5. What do you understand by the following—
   (a) Lateral conjugation
   (b) Scalariform conjugation.
6. Define homothallism and heterothallism.
7. Discuss alternation of generations in Ulva.
8. List the salient features of the life cycle of *Funaria* as a representative of the group Bryophyta.
9. Explain the term "Alternation of Generations" with special reference to the life-cycle of *Funaria*.
10. Make a diagrammatic representation of the life-cycle of *Funaria* and in it mark the gametophyte and sporophyte generations.
11. Write brief notes on the following—
    (a) Protonema of moss
    (b) Paraphysis
    (c) Annulus and stomium
    (d) Archegonia of moss.
12. Give distinctions between the following—
    (a) Gametophyte and sporophyte of moss
    (b) Protonema of moss and a multicellular filamentous alga.

13. Draw a labelled diagram of V.S. of the female receptacle of Funaria.
14. Draw a labelled diagram of the longitudinal section of the capsule of moss.
15. Justify the statement, "In moss the gametophyte is independent where as the sporophyte is partially dependent."
16. What is the advantage of paraphyses in the antheridial and archegonial heads of a moss gametophyte.
17. Give the similarities and differences between the antheridium and archegonium of a moss plant.
18. Where does the reduction division (meiosis) takes place in the life cycle of moss plant?
19. List the distinct generations observed in the life cycle of Funaria.
20. Why does the sporophyte is called parasitic on gametophyte?
21. The spores of moss plant do not germinate directly into moss plant but form an intermediate stage. Write the name of that stage.
22. How do the sperms from antheridia reach the archegonia in *Funaria*.?
23. If the moss plant contains *n* number of chromosomes, what will be the number of chromosomes in-
    (a) Leaves (b) Antheridia (c) Archegonia (d) Spores (e) Protonema.
24. Give an account of the organization of a fern sporophyte. Indicate the place where reduction division takes place in its life-history.
25. Describe the process of alternation of generations taking fern as an example.
26. Give in short the life-history of Fern.
27. Describe the mode of reproduction in fern. Add a note on dispersal of spores in fern.
28. Compare the lie-cycle of *Dryopteris* with that of *Funaria*.
29. Compare and contrast the gametophytes of fern and funaria.
30. Draw a well labelled diagram of a fern sporangium and describe the mode of dispersal of spores.
31. Describe the structure of a mature prothallus and sex organs borne by it.
32. List the distinguishing characters of *Dryopteris* which shows its advancement over *Funaria*.
33. Distinguish between the sporogonium of *Funaria* and the fern sporangium.
34. Compare the gametophyte and sporophyte of fern.
35. Indicate the relationship between chromosome number and alternation in the life cycle of *Funaria* and *Dryopteris*.
36. Describe the mode of spore dispersal from sporangium of a fern.
37. Give one important difference between a spore and a zygote.
38. Where does meiosis occurs in the life-cycle of *Dryopteris*.
39. If the number of chromosomes in the Fern sporophyte is 2n, what will be the number of chromosomes in the following-
    (a) Leaves
    (b) Sporangium
    (c) Prothallus
    (d) Embryo
    (e) Antheridium
    (f) Stomium.

Seed

Seed is the final outcome of the sexual reproductive process in flowering plants. It represents the beginning of a new generation. KOZLOWSKI and GUNN (1972) have defined seed as a fertilized mature ovule that possesses an embryonic plant, stored food material and a protective coat.

The evolutionary success of the flowering plants has been due to the development of a mechanism that protects the new generation within the old generation. Seed represents a miniature plant with an adequate supply of reserve food material for the nourishment at the time of germination. Seed is a means of perrenation. During this phase all the life activities are temporarily suspended to tide over the unfavourable and injurious climatic conditions. With the arrival of favourable conditions the seed resumes active life, germinates and grows into a new plant.

As seeds contain the miniature but dormant future plant, their dissemination is crucial for the distribution and establishment of plants over a wide geographical area.

SEED DISPERSAL

Air, water, animals and even the self explosive mechanisms help in the dispersal of seeds. On the basis of dispersing agencies, the dispersal can be of the following types—

1. Wind Dispersal—Seeds and fruits dispersed by wind have any one of the following specialities—

(1) Seeds are *small and light* in orchids.

(2) **Flattened seeds** without wings as in *Malxa*.

(3) **Winged seeds**—in Cinchona, Mapel, Sal, *Pinus, Moringa, Acer* etc. have membranous wing-like processes.

(4) **Parachute mechanism**—Seeds of *Helianthus* (sunflower) have a parachute-like tuft of hairs called *pappus* (formed by persistant calyx). In *Clemattis* the style becomes feathery. In *Calotropis* a tuft of hair, called *plume* or *coma* develops at the crown of seeds.

(5) **Censor mechanism.** In poppy the mature capsule has pores in its pericarp. The seeds are small and light. When capsule sways in the wind a few seeds escape out of the pores.

2. Water Dispersal—Fruits and seeds dispersed
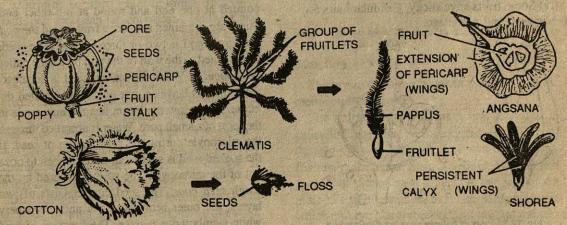
Fig. 12.1 A few seeds and fruits modified for wind dispersal.

Means of Fruits Disperal

By Air				By Animals	By Man	By Explosive Mechanism
Seeds light	Winged seeds	Hairy	Balloon-shaped	Censor mechanism		Geranium,
	Maple,	Cotton,	Physalia	Poppy		Balsam,
ex. Orchid,	Shorea	Milk-weed,				Squirting
Cinchona	Fraxinus	Clematis				cucumber
and grasses	Chilbil					

Parachute-mechanism

Edible fruits	Sticky seeds	Hooked seeds
Fig,	Peepal	Tribulus,
Neem, Oak		Xanthium
		Andropogon

by water are adapted for floating so that they are carried to distant places by water currents.

(i) The *coconut fruit* floats because its fibrous mesocarp encloses air, thus making it buyoant.

(ii) *Lotus* has a spongy thalamus with fruitlets embedded in it.

(iii) Seeds of certain water lilies have air spaces.

3. Dispersal by Animals—Birds and mammals including man help in the dispersal of fruits and seeds.

(i) Fruits of mango, orange, guava are brightly coloured and fleshy. Their succulent part is eaten by mammals and seeds are thrown away.

(ii) Some fruits develop hooks for clinging to the body as in *Xanthium, Urena* and *Mimosa*.

(iii) Some have hairs to be caught in the fur of dogs, cats as in love grass and spear grass.

(iv) Some fruits have sticky, glandular hairs as in hogweed and plumbago.
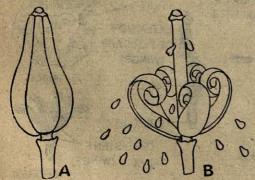
Fig. 12.2 Fruits of balsam showing dispersal by explosive mechanism.

4. Dispersal by Explosive Mechanisms—Certain fruits when ripe burst open with a jerk so that their seeds are thrown apart. *e.g. Castor, Balsam, Oxalis, Acacia* and *Caesalpenia*.

SEED STRUCTURE

Seeds vary greatly in size. They can be as small as those of orchids (about 2 million seeds per gram) or as large as those of coconut. In many plants the seed surface is differently patterned. In many plants the seeds are so peculiar that help in identification of a species.

Gram seed may be taken as an example for the study of the structure of a seed.

Gram Seed

The gram seeds are brown in colour. They are pointed at one end and round at the other end. These are contained in a small fruit called the *pod*. The gram pod is two or three-seeded. The seeds are attached to the wall of the pod by a stalk called the *funiculus*. When the mature seed is detached, the funiculus leaves a scar on the seed called the *hilum*. Just below the hilum lies the *micropyle* in the form of a small pore. Water is absorbed through the micropyle during the germination of seed. If the soaked seed is squeezed, water is seen to ooze out of the micropyle. The seed is covered by the tough *seed coat*. The seed coat consists of two layers, the outer brownish *testa* and the papery white membranous *tegmen*. The function of seed coat is protective. It protects the seed from
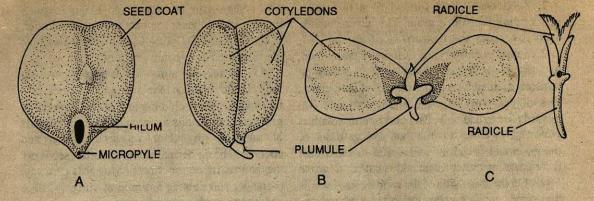
Fig. 12.3 Structure of gram seed.

desiccation, mechanical injury and extremes of temperature. It also protects the seed from the attack of bacteria, fungi and insects.

On removing the seed coat, two massive and fleshy *cotyledons* are seen. The two cotyledons are attached laterally to the *embryonal axis*. The embryonal axis projects beyond the cotyledons on either side. The lower pointed end of the axis is the *radicle* which represents the embryonic or rudimentary root. The other end is feathery. It is called the *plumule*. It represents the first apical bud of the future plant and develops into the shoot. The plumule is seen only after separating the two cotyledons. The portion of the axis between radicle and the point of attachment of the cotyledons to the axis is called the *hypocotyl* and the portion between the plumule and the cotyledons is the *epicotyl*. The axis along with the cotyledons constitutes the *embryo*.

Albuminous and exalbuminous seeds—In gram, pea and bean the cotyledons are thick and fleshy. They store food material for the use of embryo during its germination. Such seeds are known as *nonendospermic* or *exalbuminous seeds*.

However, in seeds like castor, maize and other cereals the cotyledons are thin and membranous. In such seeds food is stored in the endosperm. Cotyledons act as absorbing organs. They absorb food from the endosperm and supply it to the growing embryo. Such seeds are known as *endospermic* or *albuminous* seeds.

Dicotyledon and monocotyledon seeds—On the basis of number of cotyledons in the seed, angiosperms have been divided into two groups.

(1) **Monocotyledons** having embryo with one cotyledon only, *e.g. maize, rice, wheat* and *onion.*

(2) **Dicotyledons** having embryo with two cotyledon, *e.g., pea, gram, bean* and *castor.*
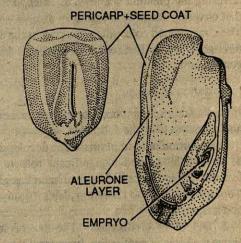
Fig. 12.4 Structure of maize grain A. Entire seed B. Grain in L.S.

Structure of Maize Grain

The maize grain can be taken as an example of monocotyledon seed.

The maize grain is a small one-seeded fruit called the *caryopsis*. In maize grain the seed coat (testa) is fused with the fruit wall (pericarp). Externally the maize grain is yellow in colour and somewhat triangular in shape. On one side of the grain is a small, opaque, oval and whitish area in which embryo lies embedded. A longitudinal section of the seed shows the following structures—

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1. Seed coat—It is formed of a thin layer surrounding the whole grain. This layer is made up of seed-coat and pericarp *i.e.*, fruit wall.

2. Endosperm—When internally examined, maize grain is found consisting of two unequal portions divided by a thin layer called epithelium. The bigger portion is the endosperm and lies towards the broad side. The endosperm which is yellowish or whitish is the food storage tissue of the grain and is rich in starch. But its outermost layer contains only protein and is called *aleurone layer*. On the other side of the endosperm towards the pointed end lies an opaque body called *embryo*.

3. Embryo—It consists of one large and shield-shaped cotyledon. This is also knwon as *scutellum* in the case of maize and other cereals. The axis of the embryo lies embedded in the scutelum. Axis consists of a *plumule* at the upper portion and the *radicle* at the lower end. Both the radicle and the plumule are enclosed in sheath. The sheath covering the plumule is known as *coleoptile* and that covering the radicle is known as *coleorhiza*. The cone-shaped coleoptile has a pore at the apex through which the first foliage leaf emerges during germination.

Importance of Seeds

Seeds are important both for the human beings and plant itself in the following ways—

1. Evolution of land plants—The development of seed habit played a significant role in the evolution of land plants. The seed habit has given a unique advantage to flowering plants for survival and dispersal.

2. Origin of civilisation—The use of seeds forms the basis of civilisation. It was neolithic man who made the first use of seeds. By sowing the seeds of cereals in the river valley he was able to provide a regular supply of food for his race. The development of agricultural practices assisted man to get rid of crude methods of food gathering and hunting of animals. This is considered to be the first step in man becoming civilised. Unlike other resources used by man which are exhaustible, plants have provided an assured supply of food to fulfil the ever increasing needs of man.

3. Source of food—Cereals and legumes are an important source of human diet. The seeds are of high nutritious value. They are rich in carbohydrates, proteins, vitamins, minerals and fat.

The cereals can be stored for longer periods because of their being compact and dry. In addition of cereals, coconuts, peanuts, almonds and walnuts are also used as a source of food.

4. Commercial value—Seeds not only provide food but they are also the source of medicines, oils, beverages, paints, clothing and other commercial products. Edible oils are obtained from the seeds of mustard, groundnut, rapeseed, cotton and coconut. The epidermal fibres of cotton seeds are the source of cotton fibres. Mustard, caraway, coriander and nutmeg are used as spices. Coffee and cocoa seeds are used as beverages.

5. In establishing species in new areas—Seeds are an important means for establishing a species in a new area. Since the plants are rooted at one place they are unable to move from place to place. Seeds have helped the plants to overcome this advantage. The seeds and fruits of many plants have evolved special devices for dispersal to far off places. The wind, water and animals help the seeds in dispersal. For example, the seeds dispersed by air are generally very light as in orchids, they may develop wings as in *Tecoma* and *Cinchona* or hair as in cotton and milk weeds. Certain fruits also develop special devices for the dispersal of seeds.

6. Means of multiplication—In most annual plants, seeds are the only means of multiplication and continued existence. These plants have a short life span of few months. During this they complete their life cycle and survive in the form of seeds. On the return of favourable conditions next year, they germinate and complete their life-cycle.

SEED DORMANCY

If all the conditions such as supply of oxygen, water and suitable temperature are favourable the seed germinates immediately. But many seeds do not germinate even under ideal conditions of oxygen, water and temperature. Such seeds are said to exhibit *dormancy*. The reasons causing dormancy can be divided in the following categories—

1. Dormancy due to seed coat—Due to impermeability of seed coat to water and oxygen, seeds fail to absorb them and utimately cannot germinate. Sometimes the hardness of the seed coat is the factor as in seeds of clover and sweet pea. In such cases, germination is delayed till the seed

coat is decayed in the soil as a result of bacterial action. In laboratory hard seed coats are softened by washing with sulphuric acid (conc.) followed by thorough washing with water.

2. Dormancy due to immature embryos— Some seeds are shed before the embryo is mature. Such seeds require an *'after ripening period'* during which certain changes occur within the seed. It may be due to some change of acidity, enzyme activity and respiratory rate or may be due to activation or production of some growth promoting hormones or may be due to inactivation of some germination inhibitory substances within seeds. Once embryo development is complete the seed then germinates without any special treatment.

3. Dormancy due to chemical inhibitors— The seeds present inside the juicy fruits such as oranges and tomatoes do not germinate while in fruit plenty of liquid is present. It is due to the presence of germination inhibitory substances. Coumarins and parascorbic acids are known to cause such inhibition. Now-a-days the practice of chilling the seeds is adopted because some of the inhibitory substances can be destroyed by cold or hot treatment.

Certain chemicals can remove the dormancy caused by inhibitors. Gibberallic acid is widely used in the brewing industry which speeds up the germination of barley seeds from which beer is brewed. Kinins, auxins, nitrates, ethylene etc., hasten germination.

4. Dormancy requiring for after ripening in dry storage—At the time of harvesting seeds of many plants are dormant but they do not require any special treatment to overcome dormancy. Just keeping them under dry storage conditions at normal temperature over a period ranging from a few weeks to several months, overcomes dormancy. Many of common cereals, such as barley, oats, wheat etc. show this type of dormancy. This type of dormancy can also be removed by removing the seed coats.

5. Dormancy requiring for chilling treatment—Many seeds of temperate species show dormancy which is overcome by chilling. Harvested seeds of apple, rose and peach will not germinate, if planted under moist conditions at 20°C but germinate if kept under moist conditions.

6. Dormancy due to light sensitivity—The germination of many seeds is affected by light. Such seeds are called *photoblastic*. The seeds in which germination is stimulated by light are called *positively photoblastic* whereas those in which germination is inhibited by light are *negatively photoblastic*.

SEED VIABILITY

Seed viability is defined as the capacity of the seed to remain capable of germination for some specific period of time. Some seeds lose viability after few weeks of their shedding while some remain viable for 1, 2, 3 or 5 years. The viability of seeds depends on the condition through which they pass, for example, some seeds cannot remain viable for long if kept in dry atmosphere. The ageing also affects viability. The reasons for the loss of viability may be denaturation and inactivation of proteins and enzymes, overdrying and exhaustion of reserve food of dormant seeds due to respiration.

QUESTIONS

1. With the help of a suitable diagram describe the structure of a gram seed. How it differs from the maiz seed ?
2. What is seed dormancy ? What factors are responsible for ending the seed dormancy ?
3. What are the various parts of seed in which food is stored ?
4. Mention various forms of seed dormancy.
5. What is the role of a seed in the life of a plant ?
6. A mature seed of maize is a miniature plant. Explain.
7. In what ways and how the seeds are useful to man ?
8. Write short notes on the following—
   (a) Albuminous seeds
   (b) Exalbuminous seeds
   (c) Seed dormancy.
9. State whether the following statements are true or false—
   (a) Dormancy of cereal grains is advantageous as it allows for their harvest, dry storage and ultimate use as food.
   (b) Gibberellins induce dormancy in the seeds of various species.

10. Mention two uses of seeds.
11. Name two examples of each—
    (a) Monocotyledon seeds
    (b) Dicotyledon seeds
    (c) Endospermic seeds
12. What is a seed?
13. On the basis of the embryo how would you identify whether a given sample of seed belongs to a dicot or monocot plant.

Differentiation and Organ Formation: Growth and Developmental Processes

INTRODUCTION

Fertilization of the egg within the female gametophyte begins the development of the flowering plant. Dividing zygote forms an embryo that takes over the space formerly held by the gametophyte. This area together with the integument forms the seed. After the first and subsequent divisions a complete embryo is formed.

While the embryo and endosperm are developing, the ovule matures, becoming a seed by the conversion of the integuments around the ovule into a seed coat. The seed enables the plant to undergo a dormant stage. Various biochemical events and environmental factors lead to dormancy. Two factors are necessary to induce germination: (i) a reversal of environmental agents inducing dormancy and the addition of a certain amount of moisture.

As the germination starts, the dormant embryo begins to push against the seed coat and the radicle emerges. The cotyledons come above the surface of the soil into the air and light due to the rapid growth and elongation of the hypocotyl.

The seedling by the division of cells and their maturation, elongation and differentiation takes the form of a young plant.

Both stems and roots have lateral branches, but lateral development in them are different. The root branch begins in the cells of the pericycle as a bud which grows out through the root tissue and breaks through the epidermis to continue growth. The perimordia that will become the leaves and buds are laid down in the stem apex.

The lateral buds can remain dormant for extended periods of time, until hormonal differences trigger germination. Once a bud germinates, its growth is indistinguishable from the main shoot. One of the interesting problems in plant development is how a long dormant bud initiates development after so many years of developmental inactivity.

The growth of the various parts of the plant obviously depend on the processes of division, elongation and differentiation. The only controls presently understood are those of hormones and light.

GROWTH

Growth is one of the most fundamental and conspicuous characteristics of living organisms. It is the net result of various processes that combine to cause and irreversible increase in mass, weight or volume. In multicellular plants growth is accomplished by the fixation of inorganic substances from the surrounding medium. So long the rate of synthesis of complex molecules, like carbohydrates and proteins exceeds their breakdown growth occurs.

Definition of Growth

Growth may be defined as a more or less irreversible change in the structure, development of a cell, tissue or organism and may involve one or more of the following—

(i) increase in the amount of protoplasm.
(ii) increase in the size of cells, their number, organs and the organism as a whole.
(iii) increase in the number of cell organelles.
(iv) increase in weight.

In plants growth takes place by cell division and cell enlargement. But increase in the size and number of cells cannot account for the development of a plant. When a seed is sown, it does not become a bigger seed but a seedling,

because growth is accompanied by differentiation. Inspite of the fact that all the cells in a plant have the same genetic structrure and are influenced by the same external environmental factors, they undertake different functions depending on their location in the plant. Certain internal cellular mechanisms inhibit the expression of certain genes whereas allows that of others.

On observing under a microscope, the differentiated cells show modifications in shape as in tracheids, absence of end walls as in vessels, perforated end walls as in sieve cells or accumulation of latex in laticiferous cells. This phenomenon of overall changes of form of the plant is known as *morphogenesis*. But the mechanism of differentiation of cells and their location in a plant is not well understood.

Phases of Growth

Growth is not a simple process. It occurs in the meristems. Meristems occupy different positions in the plant body such as apical, intercalary or lateral. During growth, meristematic cells pass through the following three phases—

1. Cell formation phase
2. Cell enlargement phase, and
3. Cell differentiation phase.

1. Cell formation phase—During this phase meristematic cells divide to form new cells. The newly formed daughter cells are thin walled, isodiametric and have dense protoplasm. The daughter cells have the same number of chromosomes, the same genetic constitution.

2. Cell enlargement—During this phase, the newly formed cells absorb water by osmosis resulting in the increased turgidity and expansion and dialation on the elastic cell wall. In the initial stages the cell enlargement occurs in all directions but is latter confined to specific directions. For example, parenchymatous cells may remain isodiametric while sclerenchyma fibres elongate several times of the original young cell.

3. Cell differentiation phase—This occurs a little lower down the zone of elongation. The thin stretched cell walls grow in thickness and then gradually undergo structural, and physiological changes depending on their location in the plant.

Thus, the cells of root hair take up the function of absorption of water and minerals, those in leaf have chloroplasts and help in photosynthesis. Likewise, elements of phloem participate in the conduction of sugar and other organic substances and xylem elements serve to conduct water and provide mechanical strength.

Experiment—Take a germinating bean seed with the radicle about 2 cm. in length. Dry the seedling with the help of filter paper and mark the root at 2 mm intervals from tip upwards with a waterproof ink. Place the seedling on moist filter paper in a petridish for 24 hours. Observe the ink marks.
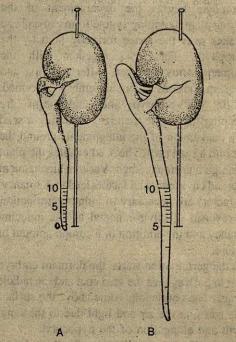
Fig. 13.1 Detection of zones of elongation in a seedling. (left) Seedling at the time of marking; (Right) Seedling after 24 hours.

It will be observed that the lines at a little distance behind the tip become widely separated from each other, while those at the tip and those higher up remain more or less intact. This clearly shows that the growth is fastest behind apex.

Growth Curve

Every organ of the plant body, infact every cell that the organ is composed of, shows a variation in the rate of its growth. Growth is slow in the initial stages. This is the *lag phase*. Now it accelerates until a maximum is reached. This is the
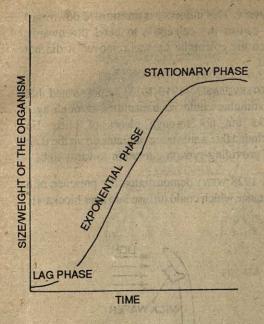
Fig. 13.2 Sigmoid growth curve.

exponential period of growth. After this the growth slows down until it comes to a standstill. This is the *stationary phase.*

Growth Rings

In perennials growth continues throughout their life. But plants shows a seasonal variation in growth. During winter, plant metabolism slows down and the plants become dormant. Growth is also affected by the length of day and night, the direction of light and gravity and availability or nonavailability of water.

Fig. 13.3 Growth rings in a stem of a perennial plant.

On the approach of favourable climatic conditions, growth is resumed. The part of the year when the plant shows maximum growth is called the *growing season.* Duration of growth season varies with the species, climatic conditions, availability of water and nutrients and the geographical location. Growth rings can be seen in the transverse section of the stem of trees. These indicate the cyclic nature of the periods of dormancy and active growth.

Trees growing in temperate and subtropical regions with marked seasonal changes show well marked annual growth rings, but these are lacking in trees growing in temperate regions.

In addition to growing season, plants also have a definite flowering and fruiting season. The onset and continuance of these processes during development of a plant are controlled by the environmental factors, internal signals, metabolism, heredity and other factors.

GROWTH REGULATORS

In all plants there occur minute quantities of certain chemical substances that regulate growth and differentiation. These are called *growth regulators* or *phytohormones.* Phytohormones can have a positive effect on a process or they may have a negative effect and inhibit the process. Thus phytohormone or a growth regulator may be defined *as an organic substance produced naturally in plants controlling growth and other functions at a site remote from its place of production in minute quantities.*

Growth regulators are either growth promoters or growth inhibitors. These are : 1. Auxins; 2. Gibberellins; 3. Cytokinins; 4. Ethylene; 5.
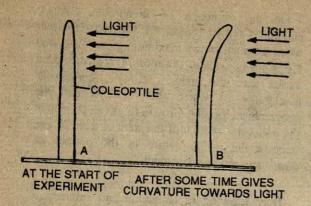
Fig. 13.4 Discovery of auxin. Darwin's experiment.

influence. This influence is transmitted downward and causes the coleoptile to bend downwards. When the coleoptile tip was removed it did not bend.

BOYSEN-JENSEN (1910-1913) demonstrated that the stimulus could be transmitted through agar blocks but not through pieces of mica. He concluded that a substance migrates down the dark side providing growth curvature towards light.

In 1928 WENT demonstrated the presence of a substance which could diffuse into agar blocks. He
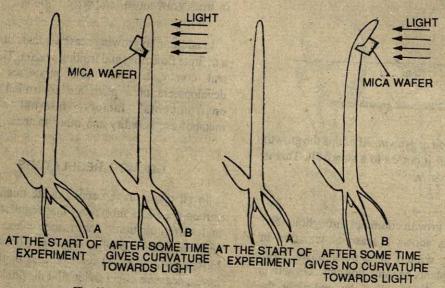
Fig. 13.5 Discovery of auxins—Experiments of Boysen-Jensan.

IAA (indole acetic acid) is the main natural auxin. It has been found in all plants studied so far and fungi. Auxin is synthesized in meristems and enlarging tissues of plants. It also occurs in the urine of persons suffering from pellagra. But the role of IAA in humans is not known.

In the last 60 years a large number of growth regulators have been isolated from plants and their action studied. The first indication of their existence was given by DARWIN (1880), who was studying the bending of the coleoptile of a grass (*Phalaris*) towards light. He found that light falling on the tip of the grass caleoptile, causes some

performed some experiments with the oat coleoptile.

1. Auxins

Among the growth regulators, auxins were the first to be discovered and studied in detail. In 1928, WENT demonstrated its effect on plant growth by performing some experiments with the oat coleoptile.

(i) When the tips of the coleoptiles were removed, no growth took place. (ii) When the freshly cut coleoptiles were placed on agar blocks for a few hours (during this period auxin diffused
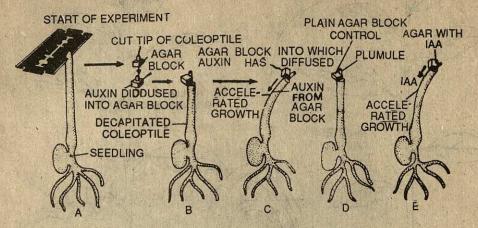
Fig. 13.6 Oat coleoptile experiment

2, 4-DICHLOROPHENOXYACETIC   NAPHTHALENE ACETIC   INDOLE ACETIC ACID = IAA
ACID = 2, 4-D   ACID = NAA

Fig. 13.7 Auxins.

into the agar block), and then the agar blocks were placed on the cut ends of the coleoptile, growth occurred. (iii) When the agar block with the diffused substance was placed laterally on the cut tip of the coleoptile, only that side of the coleoptile elongated resulting in a curvature. He also demonstrated that the degree of curvature developed by a decapitated shoot was proportional to the concentration of the diffused substance in the agar block. The experiments indicated that some substance is synthesised in the coleoptile tip and is translocated downward.

He called this substance *auxin* (from the Greek word 'auxin' to grow).

The differential effect of auxin on the growth of coleoptile and root have also been studied. In roots low concentration stimulates growth but any increase will result in retardation.

A large number of synthetic auxins are presently being used in agriculture. Some of them are—
(i) Indole acetic acid = IAA
(ii) Indole butyric acid = IBA
(iii) Naphthalene acetic acid = NAA
(iv) 2, 4-dichlorophenoxy acetic acid = 2, 4-D

Functions and Uses of Auxins

Auxins control several kinds of plant growth processes. These are as follows—

1. **Cell elongation**—Auxins promote elongations and growth of stems and roots and enlargement of many fruits by stimulating elongation of cells in all directions.
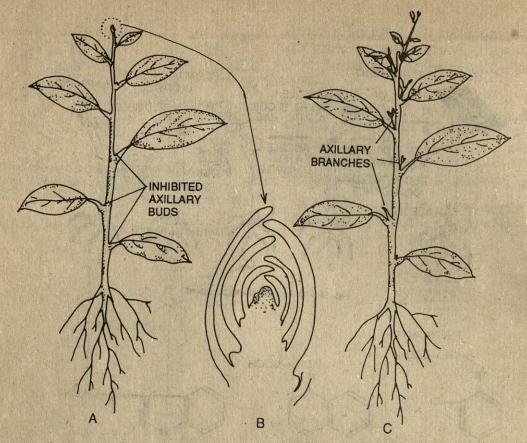
Fig. 13.8 Apical dominance in plants (A) Presence of apical bud inhibits growth of the auxiliary buds. (B) Apical bud; (C) when apical bud removed, growth of lateral buds started.
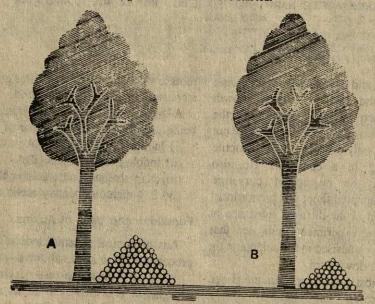
Fig. 13.9 Auxin spray prevents premature fruit absicission and increase in yield.

BROAD-LEAVED WEED KILLED BY 2.4.D SPRAY — WHEAT OR OTHER GRASS NOT INJURED BY 2.4.D SPRAY
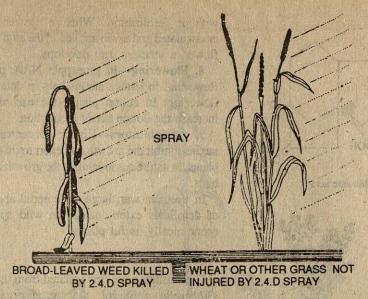
Fig. 13.10 Destruction of weeds 2, 4-D spray

CLUSTER OF FLOWERS ON TOMATO — UNPOLLINATED FLOWER — INITIATION OF FRUIT DEVELOPMENT
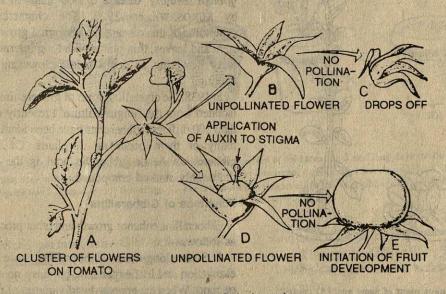
Fig. 13.11 Development of seedless fruits by auxins.

2. Reactivation of cambium—Auxins promote cell division in vascular cambium. The reactivation of cambium in the growing season is apparently triggered by IAA moving from the developing shoot buds.

3. Apical dominance—In many plants, the apical bud grows and the lower auxillary buds are suppressed. Removal of apical bud results in the growth of lower buds. The auxin of the terminal bud inhibits the growth of lateral buds. This phenomenon is known as *apical dominance*.

This property of auxins has found use in agriculture. Sprouting of lateral buds (eyes) of the potato tuber is checked by applying synthetic auxin.

4. Control of abscission layer—Formation of abscission layer at the base of petiole or pedicel results in shedding of leaves, flowers or fruits. Premature drop of fruits such as apple, pear and citrus can be prevented to a great extent by spraying the trees with a dilute solution of IAA, NAA or some other auxin.

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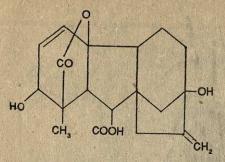
Fig. 13.12 Giberallic acid

Fig. 13.13 Cabbage plant of same age. (A) control (B) treated with GA.

5. Weed control—Weeds are undesirable in a field with a crop. Weeds cause competition for water, mineral, light and space. This causes poor yield. By the spray of 2, 4-D, broad leaved weeds can be destroyed but 2, 4-D does not affect mature monocotyledonous plants.

6. Root inducing—NAA and IBA are used for inducing the rooting in the cuttings of woody stems, e.g. rose and **Bougainvillea.**

7. Parthenocarpy—Parthenocarpy is the phenomenon of development of seedless fruits without fertilization. When a flower bud is emasculated and auxin applied to the stigma of the flower, a seedless fruit develops.

8. Flowering—In pineapple NAA promotes flowering. In lettuce auxins help in delaying the flowering. In cotton plants, the use of auxins increase the cotton seeds production.

9. As inhibitors—Higher concentrations of auxins inhibit the growth and exert toxic effect on plants. In nature auxin inhibits the growth of lateral buds.

In Vietnam war, large scale aerial application of defoliants exterminated the wild species of economically useful plants.

2. Gibberellins

Gibberellins were first isolated from the fungus *Gibberella* fujiburoi, the casual organism of *'foolish seedling'* disease of rice plants in Japan by KUROSAWA in 1926. The characteristic symptoms of this disease are abnormal growth of stem and leaves, thin plants with long internodes, early flowering or death before flowering and fruiting.

In 1938, the crystalline form of gibberellins was isolated from the fungus culture. Presently more than 100 different gibberelins have been identified, many of them occurring in plants. Of these gibberellins A_3 or gibberelic acid is the most thoroughly studied compound.

Functions of Gibberellins

Gibberellins enhance growth and other processes as follows—

1. Stem elongation—Gibberellins cause stem elongation and leaf expansion, but have no effect on roots. When the genetic dwarf varieties of plants like corn and pea are treated with gibberellins they become tall. Application of gibberellins to normal plants does not induce elongation.

Gibberellins also induce stem elongation in rosette plants. In cabbage, there is profuse development of leaves but internodes are reduced. Just prior to flowering, internodes elongatge enormously. This is called bolting. Boltind needs either long days or cold nights. When a cabbage head is kept under warm nights, it retains its rossette habit. Bolting can be induced artificially by the application of gibberellins under normal conditions.
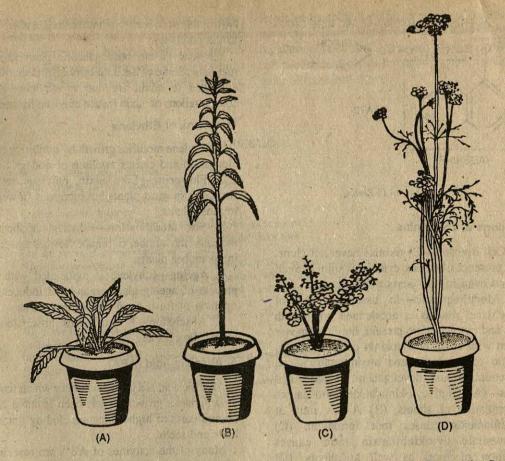
Fig. 13.14 A–B Henbane plants which usually require a period of cold treatment and long days for flowering-flowered when they were treated with Gibberellic acid as in B (No low temp, or long days were required) C-D. Carrot plants require low temperature for flowering. C. Plant without low temperature but with gibberellin spray flowered, D. Plant provided with low temperature.

2. Seed germination—Gibberellins promote seed germination in lettuce, cereals, etc.

3. Leaf expansion—Plants like pea, bean, tomato, pepper, cucumber, lettuce and cabbage on treatment with gibberellins, develop broader and elongated leaves.

4. Breaking of dormancy—Gibberellins break dormancy of buds and tubers. But in root tubers (sweet potato) the application of gibberellic acid inhibits the development of root tuber.

5. Parthenocarpy—Gibberellins cause parthenocarpy in apple and pear (pome fruits).

6. To increase the fruit size—In India gibberellins are now used to increase the fruit size

and bunch length of grapes.

7. Flowering—Gibberellins promote flowering in long day plants under unfavourable short day conditions.

8. Sex expression—In general gibberellins promote the production of male flowers in place of female flowers in monoecions plants such as *Cannabis*.

3. Cytokinins

Cytokinins regulate cell division and differentiation as given below—

Compounds that cause cell division in plant cells in cooperation with auxins are called *cytokinins*. *Zeatin* is the most common cytokinin.

ADENINE   HYDROPHOBIC SIDE CHAIN

Fig. 13.15 Zeatin.

Functions of Cytokinins

1. Cell division—Cytokinins never act alone. In the presence of auxins, cytokinins stimulate cell division even in non-meristematic tissues.

2. Morphogenesis—In tissue cultures of parenchyma, mitosis is accelerated when both auxin and cytokinin are present, but no response is seen with auxin or cytokinin present alone.

Ratio of cytokinin and auxin controls cell differentiation and development of roots and shoots— (A) High cytokinin/auxin ratio causes differentiation of shoots, (B) A low ratio of cytokinin/auxin causes root formation. (C) Intermediate cytokinin/auxin ratio causes formation of roots as well as shoots. (D) Intermediate cytokinin/low auxin causes growth of large amount of callus.

3. Breaking dormancy of seeds—Cytokinins break the dormancy of many seeds and promote their germination.

4. Apical dominance—Cytokinins, when applied externally promote the growth of lateral buds.

5. Ageing of leaves—Application of cytokinins delays ageing of leaves by controlling protein synthesis.

4. Ethylene

Ethylene enhances fruit ripening and other phenomena.

You must have seen that a ripe or injured fruit in a basket hastens the ripening of other fruits. Kerosene lamps and hay have been used by merchants to hasten colour development in fruits.

Now it has been realised that these effects are due to the ethylene.

Ethylene is the only gaseous plant growth regulator. Some of the inhibitory effects that were attributed to auxin are due to ethylene. High concentrations of auxin induce ethylene formation.

Functions of Ethylene

1. Ethylene modifies growth by inhibiting stem elongation and causes swelling of nodes.

2. **Flowering**—Like auxin, ethylene retards flowering in most plants but increases flowering in most plants.

3. **Sex modification**—Ethylene application increases the number of female flowers and fruits in cucumber plants.

4. **Ageing**—Ethylene is associated with the process of ageing plant organs and induces the ripening of fruits as in banana and citrus.

5. **Abscission**—It accelerates abscission of leaves, flowers and fruits

5. Abscisic Acid (ABA)

Abscisic acid is a growth inhibitor which retards or suppresses growth. It has been isolated from several parts of higher plants including dormant buds and seeds.

Many of the activities of ABA are reverse to gibberellic acid and cytokinins. It may inhibit the synthesis of other growth hormones, RNA and protein synthesis

Functions of ABA

1. It inhibits mitosis in vascular cambium and makes active auxillary buds to become dormant with the approach of winter.

2. It prolongs dormancy in seeds. Dormant seeds germinate when ABA is overcome by gibberellins.

3. ABA helps the plant to cope with adverse environmental conditions.

4. ABA causes temporary closure of stomata due to which there is reduction in the rate of transpiration. Thus ABA functions as antitranspirant.

Interactions among Growth Regulators

All developmental processes in plants are controlled by the growth regulators (phyto-

hormones). But phytohormones do not act singly. Instead, the developmental processes are regulated by the interactions between different growth regulators. For example abscisic acid (AB) controls abscission of leaves, flowers and fruits in plants. Auxin and cytokinin inhibit formation of the abscission layer. But the relative concentration of these regulators are critical. Similarly ratio of cytokin and auxin controls differentiation and development of roots and shoots.

QUESTIONS

1. What is differentiation? Explain.
2. Define growth. Describe growth at the cellular level.
3. Explain the role of growth regulators in plants.
4. Explain the growth curve.
5. Which of the hormone you will use to promote seed germination?
6. Why does lateral branching occurs after prunning the shoot apex?
7. List the names of growth regulators.
8. Name the curve obtaind when the rate of growth of a plant is plotted agaisnt time.
9. The growth in all plants is said to follow a set pattern. What is this pattern?
10. Auxins are supposed to promote the growth of plant or plant organs but when the roots were applied with IAA they showed retarded growth. Why?
11. Explain the role of any two growth regulators.
12. Fill in the blanks with suitable words—
    (i) The maximum growth rate occurs in .... stage.
    (ii) The process of leaf fall is known as .... and is regulated by ....
    (iii) Apical dominance in plants can be broken by cutting ....
13. Explain how the method of science operated in the discovery of auxins.
14. Elongation of genetically dwarf plants is caused by ....

Plant Development : Photomorphogenesis

PLANT DEVELOPMENT

In plant life three distinct phases can be recognised. These are—(i) seed germination and vegetative growth, (ii) reproduction phase and (iii) senescence and death.

1. Seed Germination and Vegetative Growth

Seed is the final outcome of the sexual reproductive process in flowering plants. It represents the beginning of a new generation. KOZLOWSKI and GUNN (1972) have defined seed as a fertilized mature ovule that possesses an embryonic plant, stored food material and a protective coat.

Fertilization stimulates the ovule to form a seed. The zygote develops to form an *embryo*, the primary *endosperm nucleus* by repeated divisions forms the *endosperm* and the integuments of the ovule change into the seed coat.

The evolutionary success of the flowering plants has been due to the development of a mechanism that protects the new generation within the old generation. Seed represents a miniature plant with an adequate supply of reserve food material for the nourishment at the time of germination. Seed is a means of perrenation. During this phae all the life activities are temporarily suspended to tide over the unfavourable and injurious climatic conditions. With the arrival of favourable conditions the seed resumes active life, germinates and grows into a new plant. The dormant seeds enable the plants to be carried to long distances without special precautions and damage.

Factors for Seed Germination

The essential factors for seed germination are—
(i) **Moisture of water**
(ii) **Oxygen**
(iii) **Temperature**
(iv) **Light**

1. Moisture—For germination of a seed, water is essential. In the dormant seeds, water content is only 10-15%. This keeps the concentration of the protoplasm and reserve food high. No vital activity is possible at this high concentration of protoplasm and reserve food. Adequate absorption of water converts insoluble stored food into soluble form. The soluble food is transferred readily to the growing parts.

Water also brings about the activation of the dormant protoplasm. It is necessary for respiration as oxygen reaches the protoplasm only in a state of solution in water.

Moisture softens the seed coat and the testa. Seed also swells up and embryo breaks through the softened seed-coat and comes out easily.

2. Oxygen—In the dormant condition, the respiration in seed is very feeble and the oxygen is required only in traces. But on germination when the embryo resumes its growth, the rate of metabolism is much enhanced and the seed respires vigorously. Hence the oxygen or air is required in large quantities. For this reason only the seeds which are deeply sown, fail to germinate and also a regular ploughing of the soil is essential because it aerates the ground.

3. Temperature—A suitable temperature is necessary for the germination of a seed and its further growth. For most of the seeds, optimum temperature is 25°C—30°C. Most seeds fail to germinate at temperatures below 5°C—0°C and above 45°C—50°C. There is a particular range of temperature for each seed beyond which it does not germinate.

4. Light—Light has varied effects on germinating seeds of different plants. Seeds of plants like mistletoe germinate only on exposure to light. The germination of a number of seeds is favoured by light, while in case of onion it is

hindered. There are some other seeds which are indifferent to the effect of light (*e.g.*, maize and bean).

Process of Seed Germination

When all the conditions necessary for germination are met, the first change is swelling of seed by the inhibition and osmosis of water. This causes bursting of the seed coat. Rapid respiration and secretion of enzymes causes digestion of stored food. Insoluble food is rendered soluble and complex food made simple, that can be utilised by the seedling until the latter can become photosynthetically efficient.

Based on the behaviour of cotyledons there are two types of germination—

(a) **Epigeal germination**

(b) **Hypogeal germination.**

(a) **Epigeal germination**—In this type of germination, the cotyledons come above the surface of the soil into the air and light due to the rapid growth and elongation of the hypocotyl. The cotyledons turn green and make food for a while. The food in them is utilized by the growing stem. They finally dry up and fall off and seedling becomes an independent plant. Germination of seeds of *bean, gourd, castor, cotton,* etc., is of epigeal nature.

(b) **Hypogeal germination**—In this type of germination, the cotyledons remain in the soil or just above the surface. In this case epicotyl elongates pushing the plumule upwards. The cotyledons do not turn green and gradually dry up and fall off. Common examples of hypogeal germination are the seeds of *pea, mango, groundnut,* etc.

Seed Dormancy

In several plants seeds germinate as soon as they have undergone maturation and provided proper conditions for germination. To this category belong the seeds of bean, pea, maize, etc. In many plants seeds are imcapable of germination because of some inhibitory factors. Such seeds are unable to germinate even under suitable conditions. This is called *seed dormancy*.

Breaking of Dormancy in Seeds

In some plants light plays an important role in germination. Certain varieties of cabbage and lettuce fail to germinate in darkness. But when exposed to light even briefly they germinate quickly. In such seeds the red region of visible spectrum has been found to be most effective for germination. The far-red region reverses the effect of red light and makes the seed dormant. The red and far red sensitivity of the seeds is due to the presence of a pigment called *phytochrome*.

Phytochrome is found to control several light dependent developmental processes in plants. It controls germination of light-sensitive seeds, photomorphogenesis and flowering in many plants.

Photochrome control of germination—When soaked light-sensitive lettuce seeds are given brief exposure of red (R = 660 nm) and far-red (FR = 730 nm) wavelengths, the nature of the light in the last exposure determines the response of seeds. Seeds germinate if it is red light (R) and fail to germinate if it is far-red (FR) as shown below—

R .... Germination
R + FR .... No germination
R + FR + R .... Germination
R + FR + R + FR .... No germination

The pigment phytochrome that absorbs these wavelengths of light exists in two inconvertible forms, (i) Pr form which has a light absorption peak in 660 nm and P_{fr} form which has a light absorption peak in 730 nm. On absorbing red light P_r becomes P_{fr}. Likewise P_{fr} becomes P_r either rapidly by absorbing far-red light or slowly in darkness. Germination and other phytochrome controlled processes are promoted by P_{fr}. Red light is needed to promote these processes. Darkness or 730 nm promotes P_r formation which induces dormancy and inhibits germination.

To break dormancy of such seeds, light requirement may be replaced by growth regulators such as gibberellins or cytokinins.

Mobilisation of reserves during seed germination—When seed germinates the cells of embryo resume metabolic activity and undergo rapid divisions. Stored starch, protein or fats have to be digested for the nutrition of the embryo and the seedling. This requires energy provided by aerobic respiration.

Depending upon the nature of seed, the reserves may be in the endosperm as in cereals and many monocotyledons or in cotyledons such as peas and beans. In endospermic seeds, the aleurone layer of special cells of the endosperm produces and
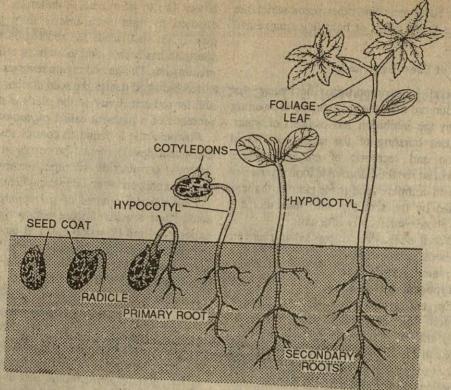
Fig. 14.1 Successive stages of epigeal germination of dicotyledonous and albuminous seed of castor.
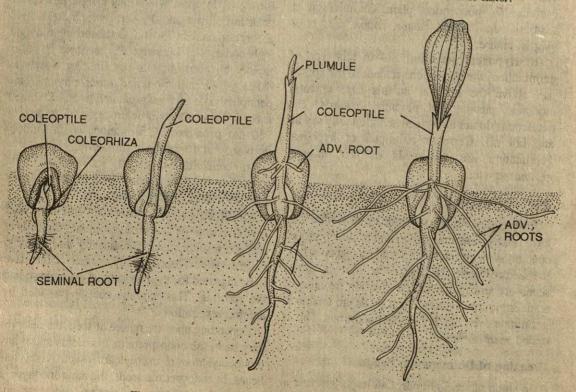
Fig. 14.2 Stages of germination of maize (hypogeal germination)
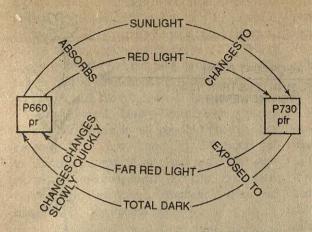
Fig. 14.3 The photochrome concept

secretes hydrolysing agents such as *amylase, proteases* which cause breakdown of starch and proteins in the inner cells of endosperm. Sugars and amino acids so formed are transported to the embryo via cotyledon. Seemingly, gibberelins play a vital role in enhancing the synthesis of hydrolysing enzymes. Thus gibberellic acid promotes germination and early seedling growth. But the dormancy-inducing hormone, ABA, inhibits the germination-promoting action of gibberellin.

It has been observed that ABA increases during the onset of dormancy of the embryo during seed formation. When young cotton embryos are removed and grown in culture, they continue to grow without any dormancy. By adding ABA, dormancy can be induced at a particular stage.

Vivipary—The seeds of some plants such as mangroves growing in marshy lands, germinate within the fruit while still attached to the parent plant. This is called *vivipary*. These seedlings falling into the marsh immediately develop roots and start growing.

REPRODUCTIVE PHASE (FLOWERING)

Reproductive phase in a plant starts with the initiation of flower primordia in the apical or lateral shoot meristems. Some plants flower in a particular season. Plants like cucumber and tomato can flower throughout the year if the temperature is adequate for their growth. Now question arises that how plants flower in a particular season and what controls their flowering.

FLOWERING

Flowering represents a radical change in the physiology of a plant. Plant shows vigorous vegetative growth until it reaches to maturity and starts bearing flowers for the purpose of sexual reproduction. The period of vegetative growth that precedes flowering varies from plant to plant. A fruiting tree takes several years for flowering whereas an annual completes its life cycle within one year. The plants such as cabbage, beet and carrot normally grow vegetatively for one season and flower in the following season. Thus, they require two seasons to complete their life-cycle and are described as biennials. Most trees are perennials. They take a few years to flower and thereafter bear flowers year after year. Plants like *Agave*, bamboos and certain palms bear flowers only once in their life time. Such plants are known as *monocarpic*. The stage of flower opening from a flower bud is known as *anthesis*.

Ripeness to Flower

The changeover from vegetative phase to the reproductive phase is influenced by several factors. These factors induce only flowering, and once it has started, further differentiation of the flower is independent of these factors.

The external conditions that are necessary for inducing flowering are called *inductive conditions*, and the period for which these conditions are required is known as the *inductive period*. The conditions under which the plant keeps itself in juvenile phase *i.e.* maintains vegetative growth is called the *non-inductive condition*.

One of the other important conditions necessary for flowering is ripeness to flower. The plant does not flower until this stage is reached. In many plants, the number of leaves borne by a plant, is a necessary condition for flowering. There seems to be a definite number of leaves for a plant before it can be induced to flower. This number varies from plant to plant. In *Xanthium*, presence of eight leaves is necessary for the plant to flower. But in some plants, it is entirely lacking. For example, *Pharbitis nil* and *Chenopodium rubrum* flower in cotyledonary condition when kept under short days for a considerable period of time. In nature, however, these plants grow into large plants before flowering.
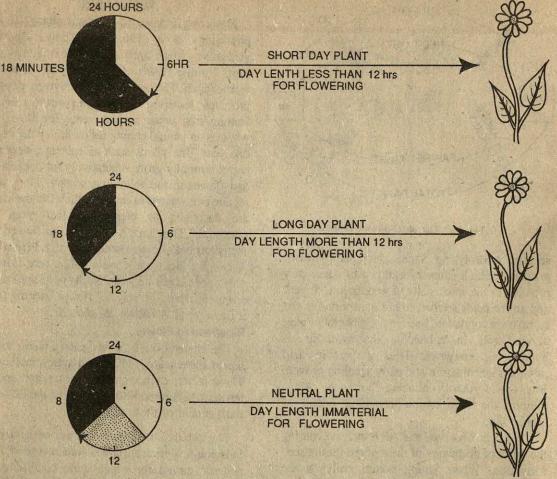
Fig. 14.4 The day-length requirements for flowering in three categories of plants.

Physiology of Flowering

The physiological mechanism responsible for flolwering has been found to be controlled by—
(i) periodicity of light (photo period), and
(ii) temperature.

Photoperiodism

The role of light has been studied in photosynthesis, growth and development where the intensity and quality of light play an important role. Similarly the length of the day light period has a marked influence on flowering. GARNER and ALLARD (1920) observed that a variety of tobacco, Maryland mammoth flowered when the relative length of the day was shorter than the length of the dark period. They used the term *photoperiodism* for the response of an organism to the relative length of day and night and

photoperiod, the favourable lengths of day for each plant. Thus photoperiodism may be defined as *response of plants to relative length of day and night.*

On the basis of the length of photoperiod requirements of plants, the plants have been classified into—
(i) **Short-day plants**
(ii) **Long-day plants**
(iii) **Day neutral plants**

1. Short-day plants—Most of the plants belong to this category. In such plants the length of the day is not as important as in the length of the night. Such plants require a relatively long period of uninterrupted darkness for flowering. *Nicotiana tobacum, Xanthium* (Cocklebur) and Soyabean are the examples of short-day plants.

2. Long-day plants—Long-day plants require

a photoperiod of more than a critical length. The critical length varies from 4 to over 18 hours for such plants. They require either a relatively small period of darkness or no darkness at all. This is supported by the fact that long-day plants usually flower best in continuous light. Beet, radish and wheat etc., are the examples of long-day plants.

3. Day neutral plants—There are many plants which can flower in all possible photoperiods ranging from few hours to 24 hours of uninterrupted light. Such plants are called *day-neutral* or *photoneutrals*. Tomato, cucumber, cotton, pea, sunflower, *Dandelion* etc. are examples of day-neutral plants.

SALIENT FEATURES OF PHOTOPERIODISM

1. Photoperiodic Induction

In short-day as well as long-day plants only a few days exposure to the appropriate photoperiod is required for inducing flowering. This kind of photoperiodic influence persists even when the treated plant is kept in unfavourable photoperiods. This phenomenon of producing photoperiodic influence on the flowering of a plant is known as *photoperiodic induction*.

2. Photoreceptor Organs

Experiments on *Xanthium* and other plants revealed that leaves are the *organs of photoreception*. The photoperiodic stimulus may be localized or systemic. In short-day cosmos plant, if a branch of the plant is exposed to short-days, and another to long-days, flowering takes place in the former and is suppressed in the latter. The effect of the photoperiodic stimulus is, therefore, *localized*. In the cocklebur plant, even if single leaf is exposed to short days and rest of the plant to long days, flowering takes place in the whole plant. Such effect in cocklebur plant is known as

NORMAL PLANT	FLOWERING	GREEN LIGHT → NO FLOWERING
PROPER LIGHT TREATMENT		
DEFOLIATED PLANT	NO FLOWERING	BLUE LIGHT → POOR FLOWERING
PLANT WITH SINGLE LEAF	FLOWERING	RED LIGHT → BEST FLOWER
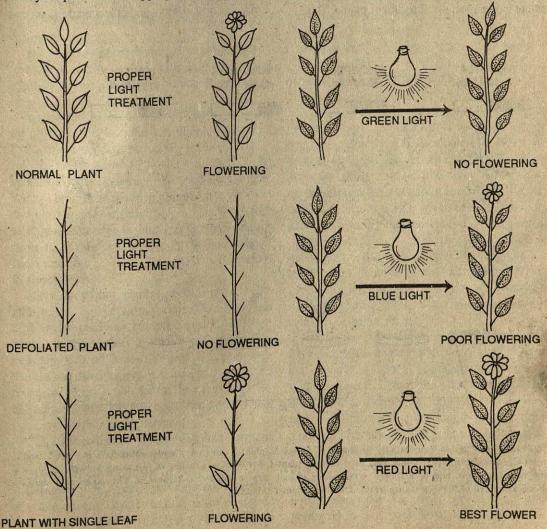
Fig. 14.5 Experiment to show that the periodic stimulus is perceived by leaves (Right)-Red light induces best flowering.

systemic.

Defoliated plants do not flower even when exposed to appropriate light whereas proper light stimulus perceived by even a single leaf is sufficient to induce flowering. It has also been observed that mature leaves are very sensitive to the photoperiodic stimulus, but young and old leaves are insensitive. /

3. Quality of Light

Green colour of the visible spectrum is normally ineffective in inducing flowering, whereas blue colour induces poor flowering. However, far-red light portion of the spectrum has been found to be most effective as a flower inducing stimulus in both the short-day and long-day plants.

4. Nature of Stimulus (Florigen)

It has been seen that though photoperiod influence is induced in leaves, flowers are formed elsewhere in the specialised region of plants. This indicates that stimulus travels from the leaves to the flower forming region. Experimental findings support the view that stimulus moves through phloem but independent to the transport of photosynthetic products.

The above stimulus is in the form of a chemical named as *florigen*. The chemical nature of stimulus is supported by grafting experiments. In an interesting experiment on *Maryland mammoth* variety of tobacco, a branch or a leaf of plant which has received the proper photoperiodic induction could induce flowering on grafting in a plant exposed to unfavourable photoperiods. By such experiments long-day plant could be made to flower under short day if grafted. The experiment also shows that the chemical nature of florigen is the same in all plants.

5. Phytochrome

BORTHWICK PARKER and others made extensive
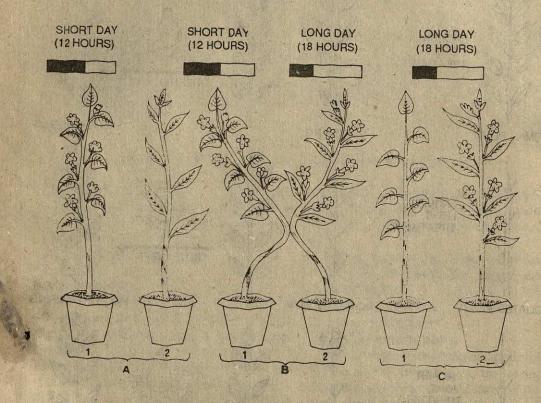
Fig. 14.6 Three sets of experiments, A, B and C. In set A, plant-1 can flower under short-days but not 2, and in set C, plant-2 can flower under long days and not plant-1. Set B shows grafting of two plants—short day plant and long-day plant, and both flower irrespective of long day or short day- treatment. The experiment shows chemical nature of florigen transportable from one plant to another.

studies on the effect of visible light on plants. It was observed that in short-day plants such as cocklebur, soyabean, *Amaranthus* and *Chrysanthemum* if red light is given in the middle of dark period, the flowering does not occur. But, later on when these plants were treated with far red light, the flowering took place. In long day plants such as barley and henbane, this effect was just opposite. When the red light was given in the middle of dark period, the flowering was increased, but when far red light was given flowering was stopped.

Above observations led them to propose that in flowering special *pigment phytochrome* is involved. Phytochrome is universal in distribution in green plants. It appears to be a protein with a chromatophore. It occurs in two forms. The form which absorbs red light (660 nm) is designated as P_r and the form that absorbs far-red light (740 nm) is termed P_{fr}.

The red absorbing form of phytochrome is blue-green and the far-red absorbing form is light green in colour. Of the two forms, P_r stimulates flowering while P_{fr} inhibits it.

In short-day plants, at the end of the light period, the phytochrome is in the far-red light form (P_{fr}'). In the following dark period, P_{fr} is converted into red absorbing form (P_r) which stimulates the synthesis of the flowering substance, the florigen. When a brief flash of red light is given to the short day plant in the mid night, P_r is converted back to P_{fr} and flowering is inhibited. On exposing the plant to far red radiation, P_{fr} is immediately converted into P_r form. This induces flowering.

6. Gibberellin

Many long day plants when supplied with gibberellin, initiate floral primordia even when kept under unfavourable photoperiod. In these plants there appears to be some connection between gibberellin and florigen. It is presumed that carbon dioxide gives rise to a precursor. The precursor leads to the formation of *gibberellin-like hormone* which is now converted into a flower inducing hormone, the *florigen*.

$$CO_2 \rightarrow Precursor \rightarrow Gibberellin\text{-like hormone} \rightarrow florigen.$$

7. Photoinductive Cycles

Different plant species have different number of photoinductive cycles to induce flowering. In short-day plant, *Xanthium*, only one photoinductive cycle is needed to induce flowering, whereas in another short-day plant, *Salvia accidentalis*, 17 photoinductive cycles are required to induce flowering. Once a plant is exposed to a definite number of photoinductive cycles, it flowers even when kept in noninductive cycles.

Certain short-day and long-day plants show partial induction when exposed to certain number of photoinductive cycles. Short-day plant, *Impatiens*, needs 3 photoinductive cycles to form flower buds but more than 8 cycles are required for flowering. In case of *Plantago*, a long-day plant, 25 cycles are needed for complete inflorescence formation. But the plant fails to flower if given only 10 such cycles and then kept in noninductive cycles.

It appears that some flowering stimulus accumulates during the inductive cycle. In *Xanthium* enough of the stimulus accumulates during one photoinductive cycle to induce flowering whereas in other plants more than one cycle is needed.

8. Importance of Dark Period

In short-day plants the length of the day is not as important as is the length of the night. Such plants require a relatively long period of uninterrupted darkness for flowering. When the dark period is less than the critical length flowering does not occur even if the light period is of appropriate length. Flowering is inhibited if a very mild intensity of light is given to such plants for some time during the dark period. The flowering is also suppressed when the dark period is interrupted midway by a single flash of light. The length of the dark period and its continuity are the factors that are important in inducing flowering in short-day plants. The short-day plants are thus also called *long-night plants*.

In long day plants, periods of darkness have an inhibitory effect on the flowering. A long-day plant can be made to flower under short-day periods by giving a flash of light to the plant during the long dark period. Further, a long-day plant which normally flowers in a day length of 16 hours of a normal 24 hours cycle of light and darkness, can also be induced to flower if given 8 hours of light of a 12 hour cycle of light and darkness.

The inhibition of flowering in a long-day plant under short-day is not because of short photoperiods but because of long dark periods.
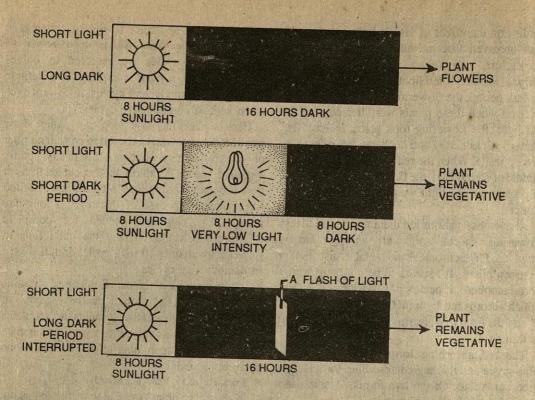
Fig. 14.7 Flowering in a short day plant is suppressed by very low intensity of light and also by a single flash of light during the long dark period.

Thus the long-day plants can justifiably be called *short-night plants*.

VERNALIZATION

Russian agronomist LYSENKO coined the term *'vernalization'* in 1929-30. According to him vernalization may be defined as *the method of inducing early flowering in plants by pretreatment of their seeds at low termperatures. CHOURAD (1960) has defined it as the acquisition or acceleration of the ability to flower by chilling treatment.*

In many plants apart from correct photoperiod, temperature is also an important factor which affects the initiation and development of reproductive organs. In case of annuals the influence of temepratures on flowering is secondary to light. The biennials show only vegetative growth during the first year and only after prolonged exposure to cold temperatures of winter they flower in the next season. Majority of plants will not flower if they are not subjected to cold temperatures and continue to grow

vegetatively for an indefinite period. However, if they are subjected to cold treatment followed by correct photoperiod, they start flowering.

The practical utility of vernalization has been fully exploited by the Russian scientists that by vernalization—

(i) crop can be produced and harvested much earlier than the control crop ;

(ii) crops can be grown in the regions where they do not naturally reproduce; and

(iii) plant breeding work can be accelerated.

Vernalization Process

For vernalization the seeds are allowed to germinate for some time and then are given cold treatment by keeping them at 0—5°C. The period of cold treatment varies from few days to many weeks from species to species. After the cold treatment seedlings are allowed to dry for sometime and then sown. The seeds should not be sown immediatley after the cold treatment. The drying period also should not be a very long one as with the increase in the drying period the

response of vernalization decreases. Devernalization is also affected by giving heat treatment to the vernalized seeds.

Though it is the stem apex that perceives the effect of vernalization, but WELLENSICK (1961-62) succeeded in vernalizing roots and leaves of *Lunaria biennis*. Vernalization also depends on the duration and temperature at which the seeds are subjected to vernalization. In some plants vernalization is affected only when some vegvetative growth has taken place.

Photoperiodism not only induces plant to flower but also initiates flowering, whereas vernalization simply prepares the plants for flowering. According to KLEB, during cold periods plants acquire a physiological state of ripeness for flowering.

Now it has been possible to vernalize the isolated embryos also. By revernalization, a shoot apex can be cultured and raised into a whole plant.

SENESCENCE AND ABSCISSION

1. Senescence

Annual and biennial plants after the production of flowers, fruits and seeds die. Many trees and shrubs shed their leaves at the end of growing season. Plants growing in temperate zone shed their leaves before the onset of winter. In other parts of the world, plants shed their leaves during the harsh summer and grows them during the wet periods which are more favourable for growth. *This phenomenon of deteriorative changes with aging is called senescence.* Thus senescence *may be defined as the period between reproductive maturity and death of a plant or plant part.* In trees, before the leaves die and shed, their proteins are hydrolyzed to yield amino acids which are then exported to stems. This is an important form of resource conservation.

Senescence, in plants, is of the following types—

1. **Whole plant senescence**, when the plants die after seed production as in wheat, rice, gram and mustard. This is also observed in monocarpic plants which live for several years but flower only once in their life time as in sago palm and bamboos.

2. **Sequential senescence**—In many perennial plants, the tips of main shoot and branches remain in a meristematic state and continue to produce new buds and leaves. The older leaves and branches senesce and die. This is called *sequential senescene.*

3. **Shoot senescence**—This is observed in perennials like bannana and gladiolus. In these plants the above ground part of the shoot dies each year after flowering and fruiting, but the underground parts (stem and roots) survive and put out new shoots next year.

4. **Synchronous senescence**—In temperate deciduous trees such as elm and maple all the leaves are shed in autumn. This is termed *synchronous senescence.*

Advantages of senescence—Old and inefficient organs are replaced by the young and developing organs. In trees, when the old leaves are shed, nutrients are withdrawn into the main trunk and diverted to the young parts later on. Shedding of leaves reduces transpiration. This is an adaptation to tide over the winter when the soil is frozen and roots cannot observe water. Leaf litter helps in recycling of matter as it releases nutrients to the soil which are used again by the plants.

2. Abscission

The process of separation of leaves, flowers and fruits from the plant is called *abscission*. It is not simply a matter of those parts breaking off. It is essential, when these parts are removed, that the plant seal off its vascular system to prevent loss of water and nutrients and to exclude bacteria, fungal spores and other pathogens. An abscission zone, a layer of specialized cells, forms at the base of each part before it is lost, to separate it from the main body. The cells in this layer die and become hardened by the deposition of lignin and suberin. So, by the time the leaf or fruit drops, the vascular system has been sealed off.

Abscission is controlled by abscisic acid (ABA), a growth regulator synthesized primarily in chloroplasts. It is a general inhibitor of many processes, and the abscission layer forms and hardens under its direction.

1. Write an essay on the phenomenon of photoperiodism in plants.
2. What do you understand by vernalization? Give some practical uses of this phenomenon.
3. With reference to flowering, what do you understand by the terms "inductive period" and "inductive condtions"?
4. Which part of the plant usually perceives the light stimulus for flowering ? How could you establish it experimentally?
5. What are long-day plants (LDP) ? If a branch from a short-day plant (SDP), after floral induction is grafted on to a non-induced LDP the former is able to induce flowering in the latter. Explain.
6. On the basis of distribution of sex, how many types of flowers are known?
7. How would you induce male flowers on a female plant and female flowers on a male plant?
8. Explain the following terms—
    (a) Vernalization
    (b) Ripeness of flower
    (c) Monocarpic plants
    (d) Biennial plants
9. Enumerate the experiment which led to the discovery of the concept of photoperiodism.
10. Do you agree with the statement that flowering is the only photoperiodic phenomenon?
11. Is the flowering stimulus same in the long-day and short-day plants ? Explain by giving suitable examples.
12. Which is more important in a flowering plant, the light period or the dark period ?
13. What is phytochrome? How does it function in controlling flowering in plants ?
14. Give a brief account of vernalization as exhibited by certain biennial plants.
15. Explain biennial bearing in mango.
16. Describe method of propogation in banana.
17. Distinguish between the following—
    (a) Perennial and monocarpic plants
    (b) Long-day and short-day plants
    (c) Photoperiodism and vernalization
    (d) Ripeness to flower and after ripening.
18. Which part of the plant perceives the light stimulus?
19. State whether the following statements are true or false—
    (a) Phytochrome is a proteinaceous pigment whcih controls flowering in all the flowering plants.
    (b) Gibberellin can replace long-day requirement in long-day plants.
    (c) A biennial plant remains in soil for two years, then it flowres, fruits, and dies.
    (d) Two examples of monocarpic plants are Agave and bamboo.
20. Fill in the blanks in the following --
    (a) The concept of vernalization was given by ....
    (b) Phytochrome exists in .... forms, one is .... and the other is ....
    (c) Long-day plants flower if they receive a light period .... than their critical requirement.
    (d) The concept of photoperiodism was given by .... and ....
21. What are the conditons necessary for seed germination ?
22. Differentiate between epigeal and hypogeal seed germination.
23. What do you understand by seed dormancy. How the dormancy in seeds can be broken ?
24. Write notes on the following --
    (a) Senescence
    (b) Abscission
    (c) Seed dormancy
    (d) Vernalization.

CHAPTER 15

Plant Movements

Everywhere in our daily life, we observe movements of living objects. Whereas animals show noticeable movements, plants do not show such movements, because the movements of plants are in the form of bending, twisting, elongation of certain parts or organs.

In plants the movements are brought about by definite internal or external stimuli. The movements which occur only in response to external stimuli are known as *induced* or *paratonic movements*. The movements which take place spontaneously without the effect of external stimuli are termed *spontaneous* or *autonomic movements*.

The length of time required for a stimulus to induce a response is termed *presentation time*. The minimum time interval after which the response to stimulus appears is called the *reaction time*. The time required for the stimulation to disappear is called the *relaxation time*.

Classification of Plant Movements

Movements which occur due to factors inherent inside the plant body itself are known as autonomic or *spontaneous movements* and those which occur due to external stimuli are known as *induced* or *paratonic movements*.

1. Autonomic movements are of three kinds—

(A) Locomotion movements
(B) Growth and curvature movements (Nutation and nastic)
(C) Variation movements.

2. Induced or Paratonic movements include—

(A) **Tactic movements** —These include phototactic, thermotactic and chemotactic.

(B) **Tropic movements** include phototropism, geotropism chemotropism, hydrotropism and thigmotropism.

(C) Nastic movements include photonasty, tghermonasty, nyctinasty, seismonasty and hyponasty.

(D) Hydroscopic movements

(E) Seismonastic movements.

AUTONOMIC OR SPONTANEOUS MOVEMENTS

(A) Locomotion Movements

Locomotion movements are limited to some aquatic plants or structures in response to inherent factors. These are free and spontaneous. Cyclosis (streaming of protoplasm), movements of cilia or flagella, motility of zoospores and gametes and amoeboid movements of plasmodial bodies are the examples of movements of locomotion.

(B) Growth and Curvature Movements

Such movements take place in the form and shape of plants or plant organs due to the differences in the ratio of growth of different parts. Such movements are *nutational* or *nastic*.

1. Nutation—Such movements are seen in twinness and climbers. In such cases the side of the supporting organ such as tendrils which remain in contact with the support grows at a slower rate as compared to the opposite side. This results in a curvature and helps in twinning round the support. Nutation can be seen in *Cuscuta* and pea plant.

2. Nastic movements—These movements are due to differences in the rate of growth on two opposite sides. Opening of the petals and circinately coiled leaves are the examples of nastic movements.

When movement occurs due to faster growth on the upper side it is known as *epinastic movement*, and when it occurs due to faster growth on the lower surface, it is known as *hyponastic movement*.

(C) Movement of Variation

Such movements take place due to changes in

the turgidity of cells. In telegraph plant (*Desmodium gyrans*), the elliptical up and down movement of the two lateral leaflets is due to the same reason.
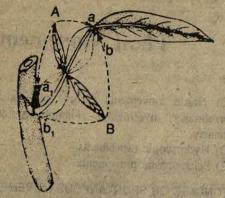
Fig. 15.1 Leaf of Desmodium gyrans showing moving leaflets.

2. INDUCED OR PARATONIC MOVEMENTS

(A) Tactic Movements

These movements occur in response to external stimuli and the direction of movement is controlled by the direction of the stimulus. These are of following types—

(i) *Phototactic* in response to light.

(ii) *Thermotactic* in response to temperature.

(iii) *Chemotactic* in response to chemicals.

(B) Tropic Movements

Tropic movements are caused by external stimulus coming from one direction only. Such movements are called *tropic movements* and the phenomenon is known as *tropism*.

Depending upon the nature of the stimulus there are various types of tropic movements. Gravity, light, water and chemical substances are the chief stimuli and the movements induced by them are known as :—

(a) Geotropism

(b) Phototropism

(c) Hydrotropism

(d) Chemotropism

Geotropism

The movement of stems and roots in response to the force of gravity is called *geotropism*. Different parts of the plant respond differently to the stimulus of gravity. Primary root always assumes the vertically downward direction. This

is known as *positive geotropism*. The shoot, on the other hand, moves just opposite to the force of gravity, thus showing *negative geotropism*. The secondary roots and branches place themselves at right angles to the force of gravity and are called as *plageotropic*. Some lateral roots and stem-branches are placed obliquely to the force of. gravity and are known as *diageotropic*. Tertiary roots are not affected by gravity and are described as *ageotropic*.
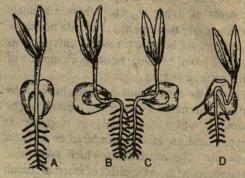
Fig. 15.2 Experiment to show geotropism.
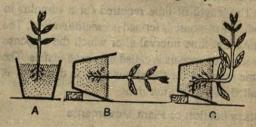
Fig. 15.3 Experiment to show that shoot is negatively geotropic.

Experiments to show geotropism—(1) Take four kernels of corn and keep them in different positions in moist saw dust as shown in the figure. Inspect them after a few days. It will be seen that all the seeds have germinated in different positions. The young root in every case will be found growing in the downward direction, thus showing positive geotropism and the young shoot in the upward direction showing negative geotropism.

(2) Take a pot containing a young plant and rest it on its side so that stem lies horizontally. After a day or two the shoot will be found growing upwards after showing a curvature. It is due to more growth on the lower surface of the curvature (Fig. 15.3) It shows that shoot is negatively geotropic.

The movement of plant organs in different directions with respect to force of gravity is due to unequal distribution of auxin and hormones. When the stem is placed horizontally, auxin, under the influence of gravity, collects more on the lower side than on the upper side. This greater concentration on the lower side promotes greater growth on that side and the stem grows upwards. But in roots, a greater concentration on the lower side inhibits the growth rather than stimulating it. The upper side having the low concentration of auxin is more favourable for growth and cell elongation. This causes the bending of root apex downwards.

If a plant is rotated on a special apparatus "*Klinostat*", to neutralize the effect of gravity, the shoot continues growing horizontally and does not show any indication of curvature. This is because of the fact that rotation causes equal distribution of auxin on all sides of the plant. The equal distribution of auxin causes equal growth on all sides and no curvature formation takes place.

Phototropism

The movement of plant organs in response to unilateral effect of light is known as *phototropism*. Most of the stems and flower stalks move towards light, and are *positively phototropic*. Most of the roots are *negatively phototropic* as they move away from light. The leaves are *transversely phototropic* as they keep their faces at right angles to the direction of light.

Experiment to show that roots are negatively phototropic—Take a small seedling of white mustard and fix it through a hole in a piece of wood or cork. Float this seedling in a beaker full of water and kep it in the phototropic chamber. After a few days, the shoot will be found growing towards light and the root away from light. This shows that roots are negatively geotropic.

Mechanism of phototropism—It is also due to unequal distribution of auxin on the two sides of the stem which forms the region of greatest growth. The auxin which is synthesized at the apex in coleoptile is distributed downwards at the region of growth. Actually the distribution of auxins is equal on both sides of the stem but it is destroyed or decomposed on the side which is exposed to

light. This causes low concentration on the exposed side and high concentration on the shaded side. Thus the growth on the shaded side is greater than on the exposed side. This results in curvature of the stem towards light.

Hydrotropism

The movement of an organ of a plant in response to the stimulus of water is known as *hydrotropism*. Roots always bend towards water, *i.e.* they are *positively hydrotropic*.

(C) Paratonic Nastic Movements

Many variation movements are induced by certain external stimuli such as light, temperature and touch. These are called nastic movements. These movements do not depend on the direction of the stimulus and are diffused.

Depending on the type of stimulus, nastic movements may be of the following types—

(i) *Photonastic* due to light.

(ii) *Thermonastic* due to temperature.

(iii) *Haptonastic or seismonactic* due to shock and touch.

(iv) *Nyctinastic* due to diurnal changes.

The diurnal movements in flowers and leaves of many plants are called *nyctinastic* movements.

Photonastic movements are exhibited by florets and leaves which open in the morning and close in the night. Flowers of certain plants open in the morning and close at night. Flowers of *crocus* and tulip exhibit *thermonastic movements* as they open at high temperature and close at low temperature. When the movements are caused by the presence or absence of light, these are called *photonastic movements*.
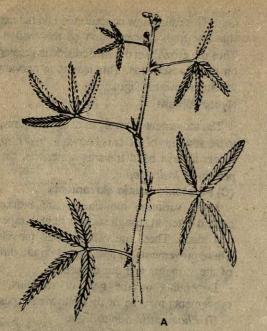
(D) Thigmonastic or Haptonastic Movements

Haptonastic movements are caused due to stimulus of touch. These are observed in insectivorous plants. In these plants the touch of other insects causes the movements to enable the plant to capture the insect.

(E) Seismonastic Movements

Seismonastic movements are best seen in *Mimosa pudica* (sensitive plant). These movements take place in response to touch.

Mimosa pudica is a herbaceous plant with bipinnately compound leaves. A swollen pulvinus is present at the base of the petiole. Smaller
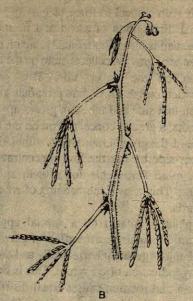
Fig. 15.4 Mimosa pudica showing seismonastic movements.

pulvinules are present at the base of the leaflets. When the terminal pinnule is touched, the stimulus is conducted to its base and then to other pinnules. The stimulated pinnules droop down in succession from the tip backwards. The stimulus then passes to other pinnules and these also droop down. If the stimulus is strong, all the leaflets are affected and the leaf as a whole droops down.

Mechanism of Seismonastic Movement—The two sides of pulvinus have different types of cellular organisation. The lower half consists of thin-walled loosely arranged parenchymatous cells and the upper half has compactly arranged parenchymatous cells. As regards the sensitivity, the vascular strand passing through this region shows upper side stable and lower side sensitive. During

normal conditions, cells of the both sides of pulvinus remain fully turgid and the leaf remains erect.

On stimulating, cells of the lower half lose water and pass it on to the intercellular spaces. As a result their turgor pressure falls. This is followed by an increase in the permeability of their membranes and decrease in the osmotically active substances in these cells which move from the vacuoles into the cytoplasm. Now the cells of the upper half absorb water from the intercellular spaces of the lower half and become more turgid. As a result of it, the upper half of the pulvinus presses down the lower flaccid half and the leaf drops down. In due course, cells of the lower flaccid half gradually reabsorb water from the intercellular spaces and become turgid and the leaf returns to its normal position after a while.

Questions

1. Describe various types of movements shown by plants.
2. What are tropic movements? Explain the role of auxin in phototropism and geotropism.
3. Write a short note on auxin in phototropism.
4. Give an account of principal types of growth movements in plants.
5. Give an account of induced movements in plants.
6. Write short notes on the following :
   (a) Phototropism   (b) Hydrotropism   (c) Nastic movements   (d) Movements of variation
7. How the leaves of Mimosa pudica react to the stimus of touch ? Explain.

CHAPTER 16

Animal Tissues

Definition

Tissue is a group of structurally similar cells that have common embryonic origin and are specialized to perform the same function or functions.

The term **tissue**(L. *texere*—to weave) was introduced by French surgeon BICHAT. The study of tissues is called **histology**. (G.*histos*—tissue; *logos*—to discourse) was given by MAYER (1819).

Basic Components of Tissues

Every tissue has two basic components:

1. **Cells** : The living component.

2. **Ground substance** or **matrix** -the nonliving component that forms **intercellular substance**.

In a **simple** tissue, all cells are alike but in a **complex tissue** two or more cell types are present together.

Classification of Animal Tissues

Based on the location and function the animal tissues are classified into four types :

S.No.	Type	Function
1.	**Epithelial Tissue**	Protection, secretion and absorption
2.	**Connective Tissue**	Support, binding, storage, protection and circulation.
3.	**Muscular Tissue**	Contraction and movement.
4.	**Nervous Tissue**	Conduction and control.

Structure

1. The cells of epithelium are closely placed and form continuous sheets.

2. These are without intercellular space and intercellular matrix.

3. These rest upon a noncellular gelatinous **basement membrane**.

4. The cells are cemented together by self secreted viscous **cementing substance**, formed of glycoprotein.

5. Plasma membranes of adjacent cells are usually connected by **tight junctions, desmosomes** or **interdigitation**.

6. Epithelial cells possess power of regeneration.

1. EPITHELIAL TISSUE (EPITHELIUM)

Position

Epithelium forms covering on external body surface and internal body organs and lines the body cavity and cavities of hollow body organs, blood vessels and ducts. The term **epithelium** (*Epi*-upon, *thelio*-to grow) was used by Dutch Anatomist RAYSCH in 18th century to denote that it grows over other tissues.

Origin

Epithelia arise from all the three germinal layers of the embryo

1. **Skin epidermis** - from **ectoderm**.

2. **Gut epithelium** - from **endoderm**.

(mucous membrane and endothelium of blood vessels)

3. **Coelomic epithelia** - from **mesoderm**.
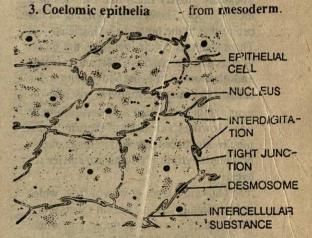
Fig. 16.1 Epithelial cells in surface view showing intercellular junctions.
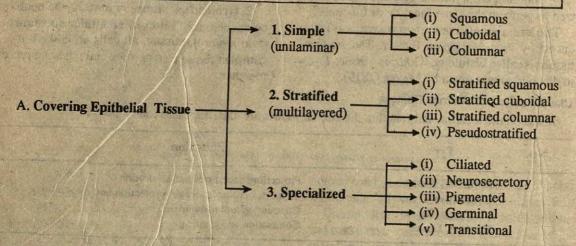
Labels: EPITHELIAL CELL, NUCLEUS, INTERDIGITATION, TIGHT JUNCTION, DESMOSOME, INTERCELLULAR SUBSTANCE

A. Covering Epithelial Tissue

1. **Simple (unilaminar)**
   - (i) Squamous
   - (ii) Cuboidal
   - (iii) Columnar

2. **Stratified (multilayered)**
   - (i) Stratified squamous
   - (ii) Stratified cuboidal
   - (iii) Stratified columnar
   - (iv) Pseudostratified

3. **Specialized**
   - (i) Ciliated
   - (ii) Neurosecretory
   - (iii) Pigmented
   - (iv) Germinal
   - (v) Transitional

1. Simple or Unilaminar Epithelium

It is composed of only one layer of epithelial cells. It is of the following types :

(i) **Simple squamous epithelium** : It is formed of a single layer of flattened , plate-like or scale-like (*squama*—scale) polygonal cells. These are closely fitted like the tiles in a mosaic floor. The cells are bulging in the centre due to the presence of nucleus.

The squamous epithelium lines the blood vessels and lymphatic vessels and is called **endothelium**. It lines the body cavity and is called **peritoneum**. It covers visceral organs and is designated as **mesothelium**. It lines Bowman's capsules of the uriniferous tubules air spaces (alveoli) in lungs, membranous labyrinth of internal ear and lens of eyes.

The outermost layer of skin of frog, which is periodically cast off as thin sheets and is demonstrated as the squamous epithelium is actually a part of stratified squamous epithelium.

The squamous epithelium helps in **protection, absorption, filteration and exchange of gases.**

(ii) **Simple cuboidal epithelium** : It consists of a single layer of isodimetric cubical cells with centrally located, rounded nucleus.

It lines the cavity of convoluted part of uriniferous tubules, smaller bronchi of lungs, thyroid gland, sweat glands and the internal ear. It carries out the functions of secretion, absorption and excretion (Fig. 16.3).

(iii) **Simple columnar epithelium** : Its cells are long and pillar-like. Their height exceeds their width. Their nuclei are also elongated and lie in the basal part.

Columnar epithelium forms mucous membrane of alimentary canal. It contains mucous secreting **goblet cells**. The free ends of columnar cells of intestinal mucosa have striated border being produced into numerous **microvilli** (brush border). These increase absorptive surface.
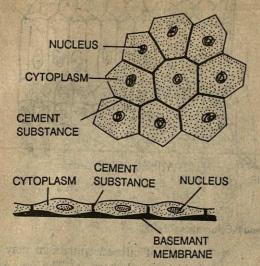
Fig. 16.2 Simple squamous epithelium layer
A- Surface view
B- Vertical section.

Fig. 16.3 Simple cuboidal and simple columunar epithelium.

2. Stratified or Compound Epithelium

The compound epithelium is formed of several layers of epithelial cells. Its innermost layer is formed of continuously **proliferating cells** and is known as **germinative layer** or **Malphigian layer**.

It is found on those surfaces where constant replacement of cells is needed due to rapid wear and tear. The epidermis of skin, the lining of mouth, oesophagous, vagina, female urethra and cornea are lined with stratified epithelium.

The basic function of stratified epithelium is protection against drying, mechanical injury or abrasion :-

(i) **Stratified squamous epithelium** : It is found in the epidermis of skin and lining of buccal cavity, pharynx, oesophagus, vagina. The cells of **germinative layer** are cuboidal or columnar. These divide continuously adding new layers of cells towards outer side The cells of outermost layer are squamous and those of intermediate layers are polyhedral. The cells of surface layer are sloughed off by friction and are replaced by underlying cells.

The stratified squamous epithelium of skin is **keratinized**, while that of mouth, oesophagus and vagina is **nonkeratinized** (Keratin is a fibrous protein progressively accumulated in upper layers of skin and makes it **water proof**.)

(ii) **Stratified cuboidal epithelium** : It is found in the conjuctiva of eyes, lining of ducts of sweat glands, mammary glands and female urethra. The cells of outermost layer are cuboidal.

(iii) **Stratified columnar epithelium** : It is found in some parts of larynx, epiglottis and the ducts of large glands. It comprises of several layers of columnar cells.

(iv) **Pseudostratified epithelium** : It appears to be multilayered, but some of its cells extend from the basement membrane to the
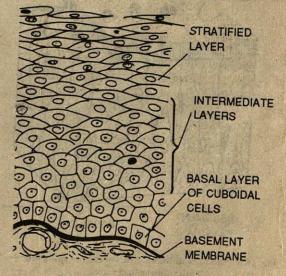
Fig. 16.4 Stratified squamous epithelium.

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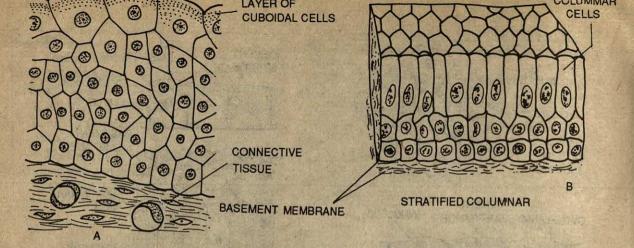
Fig. 16.5 A. Stratified Cuboidal and B. Columnar epithelium

surface, which others do not. Their nuclei lie at different levels giving it a multilayered appearance. Its cells are mostly ciliated and contain goblet cells.

It lines upper respiratory tract (*i.e.* nasal cavities, trachea and bronchi), vasa-deferentia and epididymis. Pseudostratified epithelium serves to conduct mucus or other fluids.

3. Specialized Epithelia

(i) **Ciliated epithelium** : Its cells bear cilia at their free surface. Cilia exhibit incessant movement and help in conduction of mucus and other substances.

The cells of ciliated epithelium may be cuboidal or columnar (a) The **cuboidal ciliated epithelium** is found in neck region of uriniferous tubules and keeps the urine moving. (b) The **columnar ciliated epithelium** lines oviduct, retina of eye and buccopharyngeal cavity of frog.

(ii) **Sensory or Neurosensory epithelium** : This is modified columnar epithelium with **sensory cells** interspersed singly or in groups. The sensory cells are produced into **sensory hairs** at their free ends to receive stimulus. Their basal ends are connected with the nerve fibres of sensory nerves.

Fig. 16.6 Pseudostratified ciliated columnar epithelium—
Three dimensional view.
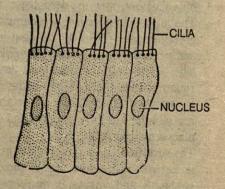
Fig. 16.7. Ciliated columnar epithelium
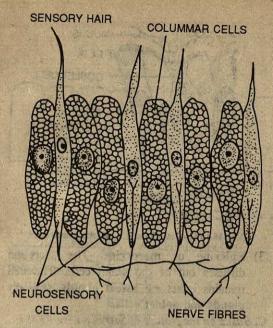
Fig. 16.8 Neurosensory epithelium

Fig. 16.9 Transitional epithelium.

Sensory epithelium is found in the retina of eye, olfactory epithelium (**Schneiderian membrane**) of olfactory organs, the lining of internal ears and mucous membrane of tongue.

(3) **Pigmented epithelium :** Its cells possess pigment. It forms basal layer of retina of eye.

(4) **Germinal epithelium :** It is specialized cuboidal epithelium. Its cells divide and redivide to produce gametes. It lines ovary and the seminiferous tubules of testes.

(5) **Transitional epithelium :** It is found in the wall of those organs which are subjected to mechanical changes due to contraction and distension. The wall of ureters, urinary bladder, upper part of urethra is formed of transitional epithelium. In contracted condition it appears multilayered like stratified epithelium but in distended condition only 2 or 3 layers are visible. There is no basement membrane. The cells rest on the connective tissue.

B. Glandular Tissue
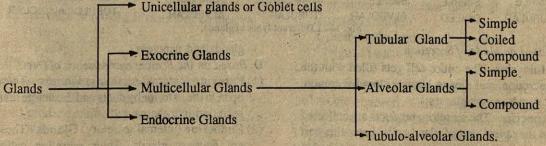
Cells of columnar epithelium modified to secrete some substance form **glandular tissue** or **glandular epithelium**. It lines the glands.

1. Unicellular Glands

These are isolated gland cells, scattered in columnar epithelium. These are called **goblet cells**. These secrete mucus. The goblet cells are found in the mucous membrane of stomach, intestine and rectum.

2. Multicellular Glands

These are groups of gland cells. These develop by the invagination of epithelia. These may be classified on the basis of structure, nature of secretion and presence or absence of duct.

```
                    ┌──→ Unicellular glands or Goblet cells
                    │                                                              ┌──→ Simple
                    │                                            ┌──→ Tubular Gland ──→ Coiled
                    │                                            │                 └──→ Compound
                    │       ┌──→ Exocrine Glands                 │                 ┌──→ Simple
Glands ─────────────┼───────┼──→ Multicellular Glands ──────────→├──→ Alveolar Glands
                    │       │                                    │                 └──→ Compound
                    └───────┴──→ Endocrine Glands                └──→ Tubulo-alveolar Glands.
```

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A. Classification Based on the Shape of secretory unit:

(1) **Tubular glands**—Secretory unit tube-like.
 (i) **Simple tubular glands**—unbranched tubular glands; found in the large intestine.
 (ii) **Simple coiled tubular glands**—The glandular part is tubular and coiled; *e.g.* sweat glands of skin.
 (iii) **Compound tubular glands**—branched tubular glands; *e.g.* sebaceous glands of skin and fundic glands in stomach.

(2) **Acinous glands**—secretory units rounded.
 (i) **Simple acinous glands**—unbranched *e.g.* cutaneous glands of frog's skin.
 (ii) **Compound acinous glands**—branched *e.g.* liver, some gastric glands.

(3) **Alveolar glands**—Secretory units flask-shaped.
 (a) **Simple alveolar glands**—unbranched.
 (b) **Compound alveolar glands**—branched *e.g.* salivary glands of mammals, pancreas.

(4) **Tubulo-alveolar glands:** Mixed *e.g.* mammary glands, Bartholin glands and Cowper's glands.
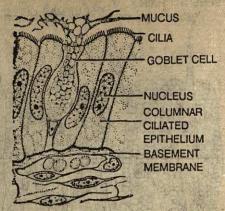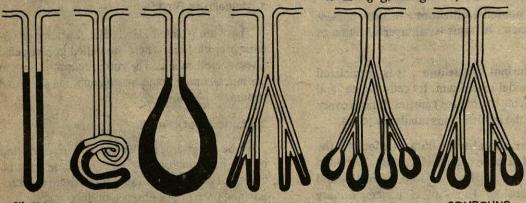
Fig. 16.10 Goblet cells or Unicellular gland cells

(3) **Epicrine or merocrine**—The secretion diffuses out of the gland cells. The cell remains intact *e.g.* sweat glands, salivary glands and goblet cells.

C. Based on the Nature of Secretion

(1) **Secous glands** - Secrete watery fluid *e.g.* sweat glands, intestinal glands and parotid glands.

(2) **Mucous glands** - Secrete mucous, a viscous slimy fluid. *e.g.* goblet cells of gut epithelium, cardiac and pyloric glands.

(3) **Mixed type glands** - Secrete both serous and mucus *e.g.* gastric glands, mandibular salivary glands and pancreas.

SIMPLE TUBULAR   SIMPLE COILED   SIMPLE ALVEOLAR   COMPOUND TUBULAR   COMPOUND ALVEOLAR   COMPOUND TUBULO- ALVEOLAR

Fig. 16.11 Different types of glands.

B. Based on Mode of Secretion

(1) **Holocrine**- The entire cell gets filled with the secretion, and dies to liberate stored secretion, *e.g.* sebaceous glands.

(2) **Apocrine**- The secretory products are collected in the apical part of gland cells. Later this part breaks off releasing the secretion. *e.g.* mammary glands.

D. Based on the Presence or Absence of Ducts

(1) **Exocrine (external secretory) Glands** - These open to the exterior by ducts and discharge their secretion into the cavity.

(2) **Endocrine (internal secretory) Glands** - These are ductless glands. Their secretion called hormone is released into the blood.

MEROCRINE   **APROCRINE**   **HOLOCRINE**
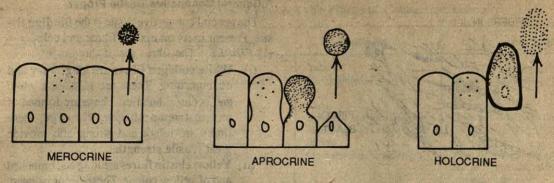
Fig. 16.12 Holocrine, apocrine and epicrine glands.

SECRETION DISCHARGED INTO A DUCT — DUCT

EXOCRINE-GRAND

SECRETION REGION

DISCHARGED SECRETION INTO A BLOOD VESSEL — LOST EPITHELIAL CONNECTION

ENDOCRINE GLAND

CAPILLARY

PRODUCE HORMONES
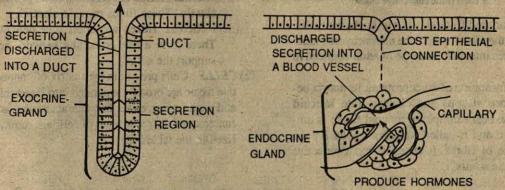
Fig. 16.13 Difference between exocrine and endocrine gland .

2. Connective Tissue

(Binding and supporting tissue)

Position

The **connective tissue** is binding and supporting tissue. It is distributed throughout the body, located in and around every body organ.

Structure

The connective tissue is formed of three components : the **cells, matrix and fibres.**

1. **Connective tissue cells :** These are found scattered in the matrix and carry out following functions :
   (i) produce intercellular matrix of connective tissue,
   (ii) store fat,
   (iii) produce new blood cells,
   (iv) ingest bacteria and cell debris,
   (v) form anticoagulant,and
   (vi) produce antibodies, antitoxins and histamins.

2. **Matrix :** It is nonliving intercellular substance. It may be homogeneous amorphous and gelatinous or may appear semifluid, mucoid or rigid.

3. **Fibres :** Three types of fibres are found scattered in the matrix.

Functions

1. Connective tissue binds different tissue in an organs and acts as a **packing material.**

2. It is called a **supporting tissue** because it binds different organs and keeps them in proper position.

3. It stores fat (**adipose tissue**).

4. It provides hard surface for the attachment of muscles (**skeleton**)

5. It protects the body against germs and other foreign substances, toxins etc.

Origin

The connective tissue of adult is derived from embryonic connective tissue called **mesenchyme** which develops from the **embryonic mesoderm.** The term **mesenchyme** was used by HERTWIG in 1883. Mesenchyme is formed of diffused network

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FIBERS IN JELLY

FIBRO-BLAST
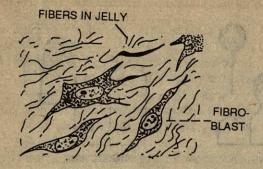
**Fig. 16.14 Mesenchyme tissue
(the embryonic connective tissue)**

of irregular undifferentiated **mesenchyme cells.**
During further development the mesenchyme gradually changes into different type of adult connective tissues.

By the formation of mucoproteins, its matrix becomes more viscous and changes into **mucoid tissue.** The best example of mucoid tissue is umbilical cord and is called **wharton's jelly.** By the appearance of fibres, it changes into connective tissue of the adults.

A. General Connective Tissue Proper

The general connective tissue is the **binding tissue.** Present in its matrix are fibres and cells.

(1) *FIBRES :* The fibres are of three types
  (i) **White collagen fibres** are long, wavy and nonbranching. These are glistening white and occur in bundles. These are formed of protein **trophocollagen.** Therefore, these fibres are tough and strong and provide great **tensile strength.**
  (ii) **Yellow elastin fibres** are long and branched and of yellow colour. These occur isolated. There are formed of an albuminoid protein, **elastin.** These fibres provide **elasticity.**
  (iii) **Reticular fibres** are short and delicate. There form a fine branching network and support the cells.
(2) *CELLS :* Cells present in the matrix of connective tissue are broadly separated into **fixed cells** and **wandering cells.** The characteristics and functions of different types of cells are summarized in the table 3.2

Types of Connective Tissue

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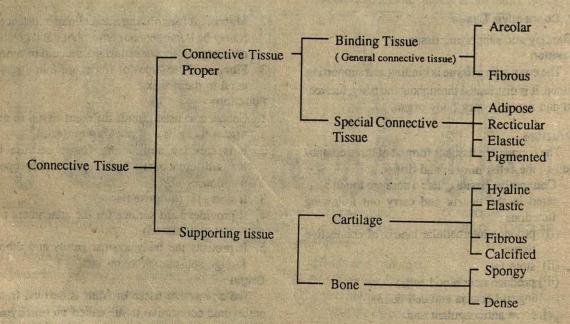
Table 3.1 : Difference between the Fibres of Connective Tissue

S.No.	Nature	Collagen fibres	Elastin fibres	Reticular fibres
1.	Colour	Glistening white.	Yellow	White
2.	Protein	Formed of protein trophocollagen	Elastin protein	Protein - reticulin.
3.	Occurrence	Occur in bundles.	Singly	Singly
4.	Nature	Unbranched	Branched and anastomosing	Branched and form a network
5.	Fibres	Thick, long and wavy	Thin, long and straight	Short
6.	Elasticity	Tough and nonelastic	Elastic	Delicate
7.	Location	Most abundant in tendons	Most abundant in ligaments	Most abundant in the embryo and in lymphoid and blood forming tissue.

MESEN-CHYME   FIBRO-BLAST   MACRO-PHAGE   LEUCO-CYTE   PLASMA CELL   MAST CELL   FAT CELL (SIGNET)   CHROMATO-PHORE
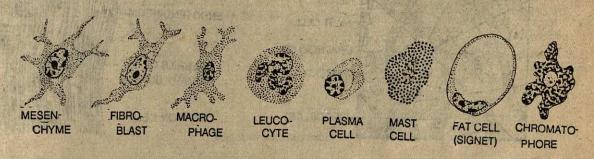
Fig. 16.15 Different types of cells found in connective tissue.

Table 3.2 : Different types of Connective Tissue Cells

S. No.	Cell Type	Structure	Function
1.	Fibroblast	Large, flattened and stellate cells with oval nucleus.	Secrete fibres and matrix.
2.	Macrophages (histiocytes)	Large, amoeboid cells with void nucleus; the processes are short and branching.	Ingest cell debris, bacteria and foreign matter. (scavengers)
3.	Lymphocytes	Migrated cells from the blood: small and rounded, move by pseudopodia.	Ingest cell-debris, bacteria and foreign matter and form antibodies
4.	Plasma cells	Small, round, or irregular cells similar to lymphocytes but large.	Produce antibodies
5.	Mast Cells	Found near blood vessels, lymphatics and nerves; large, round oval or polygonal cells; cytoplasm contains large granules.	Produce histamine, seratonin and heparin. Histamine dilates and seratonin constricts blood vessels. Heparin prevents coagulation of blood inside blood vessels.
6.	Adipose Cells	Specialized fibroblasts with a large droplet of fat; nucleus shifted to one side.	Store fat.

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Loose Connective Tissue

1. **Areolar Tissue** - The areolar tissue is most abundant in the body. It is found in the mesenteries, in omenta of the alimentary canal and in the subcutaneous tissue,. It forms frame work of all body organs and is a packing between organs. It lies along blood vessels and nerves.
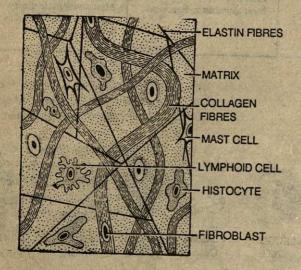
Fig. 16.16 Areolar Tissue.

Its matrix is thick, homogeneous and transparent. It contains white and yellow fibres. The connective tissue cells found are fibrocytes, histocytes, plasma cells and mast cells.

The areolar tissue forms a membranous covering around the visceral organs and binds them together. It form a medium through which exchange between blood and tissue cells takes place. It protects the body against infection and helps in maintaining water balance.

2. **Fibrous Connective Tissue (Dense Connective Tissue)**—The dense connective tissue possesses closely packed fibres in the matrix and fibroblast cells. It occurs in the form of sheets, bands and cords and is found in the dermis, capsules around certain organs and in tendons and ligaments.
   1. **Dense irregular connective tissue** - contains irregularly arranged collagen fibres. It is found in the dermis of skin and in the periosteum and perichondrium.

2. **Dense regular connective tissue.** In it fibres are arranged in parallel bundles. It may be-
   (i) **Collagenous fibres tissue :** contains densely packed bundles of collagen fibres that run parallel. The **fibroblast** cells form continuous rows in between them. It is very tough and elastic. It occurs in **tendons and aponeurosis.**
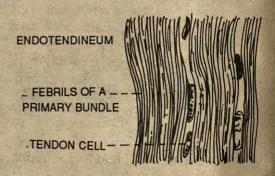
Fig. 16.17 Section of tendon to show white collagen tissue.

The **tendons** are glistening white, tough and inelastic bands at the and of muscles. These connect muscles with the bones.

In **aponurosis,** the fibres form broad sheets. It occurs in pericardium, duramater, cornea of eye ball and capsule of kidney.
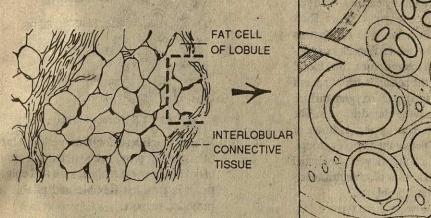
   (ii) **Yellow elastic tissue** is formed predominantly of yellow elastic fibres arranged parallel, but the fibroblasts are scattered among them. This tissue is found in **ligaments** and in the wall of blood vessels and lungs. The **ligament** connects the bones together.

B. Specialized Connective Tissues

1. **Adipose tissue :** In adipose tissue fibres are scanty. The cells are large and closely packed. These store fat in the form of large **fat globule,** the latter squeezes the cytoplasm to the periphery and nucleus to one side. The adipose tissue

lies beneath the skin in the mesentery around the viscera, in fat bodies of frog and yellow bone marrow. It forms a padding between the organs and around viscera.

The adipose tissue contains reserve food, insulates the body against heat loss, protects the joints against friction.

3. **Pigmented tissue :** It is modified areolar tissue. The cells are large and stellate and contains pigment granules. Therefore, these are called **chromatophores.** The pigment may be black, brown, blue, golden or white.

Fig. 16.19 Adipose Tissue.

2. **Reticular tissue :** It consists of star-shaped **reticular cells.** Their protoplasmic processes join to form a network. The **reticular fibres** are small and branching and form a network. The spaces of the network are occupied by fluid matrix, which contains other varieties of connective tissue cells. Reticular tissue forms the supporting frame work of lymph glands, spleen and bone marrow.
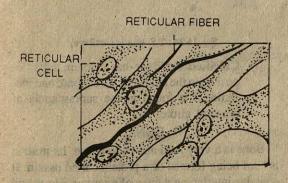
Fig. 16.20 Reticular tissue.
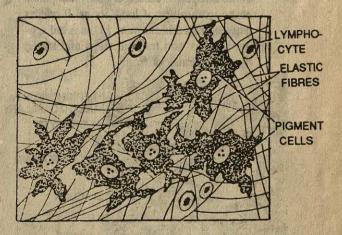
Fig. 16.21 Pigmented tissue.

Supporting Connective Tissue or Skeletal Tissue

The skeletal tissue forms a strong framework. It supports the body, protects vital organs and provides hard surface for the insertion of muscles. the skeletal tissue occurs in two forms : **Cartilage** and **bone**.

Cartilage : The matrix of cartilage is called **chondrin**. It is tough, transparent and homogeneous, formed of a special glyco-protein **chondromucoid**. It is secreted by cartilage cells or **chondriocytes**. These are enclosed in fluid filled spaces, called **lacunae**. The cartilage is bounded externally by white fibrous connective tissue called **perichondrium**. the blood vessels are present in the perichondrium but not in the matrix. The food and oxygen diffuse through matrix to reach the chondriocytes. The cartilage increases in size by the addition of new layers of matrix below the perichondrium, by the division of chondriocytes (interstial growth) and by the addition of chondrioblasts from the perichondrial fibroblasts.

The cartilage is of following three types :

(i) **Hyaline cartilage** is glassy bluish - white. Its **matrix** is homogeneous translucent fibreless and somewhat elastic. Hyaline cartilage forms the embryonic skeleton. In adult it is found on the articular surface of bones and forms cusion or epihyseal plates at the extremities of long bones. It occurs between ribs and sternum, in the nasal septum, larynx and tracheal rings and in the hyoid apparatus of frog.
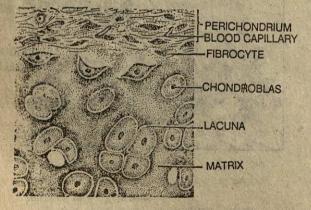
Fig. 15.22 : T.S. hyaline cartilage.

(ii) **White fibrous cartilage** contains thick, dense bundles of collagen fibres in the matrix. It is very firm. It is found between the vertebrae, where it acts as a cushion and makes the joints strong and in the symphysis it provides flexibility.
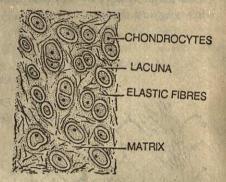
Fig. 16.23: T.S. fibrous Cartilage.

(iii) **Elastic cartilage** contains yellow elastin fibres which provide elasticity. It is found in external ear, eustachian tube and epiglottis. it is firm but flexible and pliable and provides support.
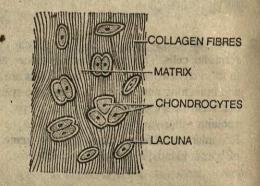
Fig. 16.24 : T.S. elastic cartilage.

(iv) **Calcified cartilage** has calcium salts deposited in the matrix. It is very hard and inelastic. It is found in the suprascapula of pectoral girdle.

BONE

Bone is a very hard and rigid tissue. Its **matrix** is hard being formed of a protein called **ossein**. It contains interlacing white **collagenous fibres** and

Table 3.3 : **Differences between different types of cartilages**
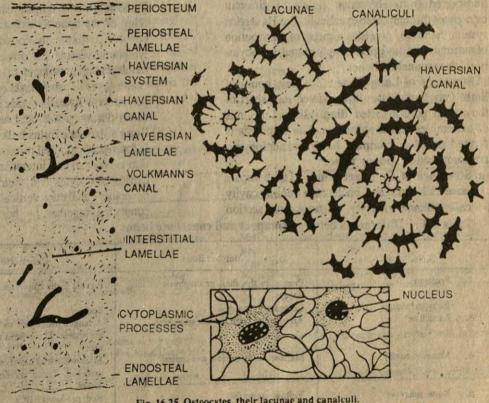
S.No.		Hyaline	Fibrous	Elastic	Calcified
1.	Appearance	Glassy or translucent	Opaque	Opaque	Opaque
2.	Colour	Bluish-white	Glistening-white	Yellowish	White
3.	Fibres	Either absent or very thin and few.	Numerous white collagen fibres	Numerous yellow elastin fibres	No fibres *Ca* salts deposited in the matrix.
4.	Elasticity	Flexible	More firm	Most flexible	Hard and nonelastic
5.	Location	On the articular surfaces of long bones, between ribs, sternum, nose, larynx and trachea.	Between the vertebrae and at the pubic symphysis	In the external ear, eustachian tube and epiglottis	Suprascapula of pectoral girdle.

is heavily deposited with salts of calcium and phosphorous. The organic and inorganic matter in the matrix form about 30% and 70% respectively. The bone cells are called **osteocytes**. These are stellate cells and each of them is enclosed in a small cavity, the lacuna. These are connected together by several fine and branched **canaliculi**. Fine processes of osteocytes extend through these canaliculi and are connected with the processes of other osteocytes.

Haversian System (Fig.16.25) : In mammalian bone the calcified matrix is deposited in the form of lamellae. These **lamellae** are arranged in three fashion:

   (i) **Haversian lamellae** - Some lamellae are arranged in concentric cylindrical layers

PERIOSTEUM
PERIOSTEAL LAMELLAE
HAVERSIAN SYSTEM
HAVERSIAN CANAL
HAVERSIAN LAMELLAE
VOLKMANN'S CANAL
INTERSTITIAL LAMELLAE
CYTOPLASMIC PROCESSES
ENDOSTEAL LAMELLAE

LACUNAE
CANALICULI
HAVERSIAN CANAL
NUCLEUS

Fig. 16.25 Osteocytes, their lacunae and canaliculi.

round numerous canals. These canals are called **Haversian canals** and the lamellae around them are called **Haversian lamellae.** Each Haversian canal with its lamellae forms **Haversian system.** Haversian canals extend parallel to the long axis of the bone and are traversed with minute blood vessels. The lacunae are arranged in between the lamellae.

(ii) **Interstitial lamellae** - These are present between Haversian systems and do not have concentric arrangement.

(iii) **Circumferential lamellae** - These lie parallel to the circumference of the bone.

Significance of Haversian System : The lacunae are connected with each other and with the Haversian canal through their canaliculi. The blood vessels reaching upto Haversian canals bring oxygen and nutrient substances, which then diffuse in the lymph. The substances dissolved in lymph are transported from Haversion canals to different osteocytes through these canaliculi. The Haversian system therefore, provides a mean of distribution of nutrients and oxygen to deeply seated osteocytes in thick mammalian bones.

Structure of Long Bone : The long bones of limbs (say femur) are differentiated into shaft or the central portion called **diaphysis** and the ends or extremities called **epiphysis.** The diaphysis is formed dense **or compact bone** and epiphyses are composed of **spongy bone.**

(a) Structure of Compact bone - The compact bone is hollow and encloses a central cavity called **marrow cavity.** Its transverse section

Fig. 16.26 Bone- Three dimensional view.

presents following layers :

(i) **Periosteum** is the tough membraneous covering of the bone. It is formed of fibrous connective tissue. It contains blood and lymphatic vessels. periosteum is absent at the articulating surfaces.

(ii) **Outer layer of osteoblasts cells** lies next to periosteum. Its cells divide and form new bones during growth and repair.

(iii) **Bony substance** forms bulk of the bone. It is formed of calcified matrix differentiated into Haversian and interstital lamellae and carries osteocytes and their lacunae. The haversian canals are vertical tubes and are connected together by horizontal canals

Table 3.4 :   **Differences between compact and cancellate bones**

S.No.		Compact Bone	Cancellate Bone
1.	Position	Present in the shaft or diaphysis of long bones.	Present in the epiphyses of long bones.
2.	Bony substance	Compactly arranged	Spongy
3.	Lamellae	Arranged to form Haversian system.	Arranged irregularly so Haversian systems are absent. These form trabeculae or spicules.
4.	Marrow cavity	Marrow cavity narrow and central	Marrow cavities broad many and irregularly arranged. These traverse the bony substance.
5.	Bone marrow	Yellow, stores fat.	Red; produces RBCs

called Vokmann's canals.

The blood vessels from periosteum pass
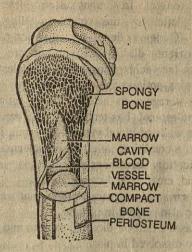
Fig. 16.27. V.S. Long bone

through the Volkmann's canal and enter Haversian canals.

(iv) Inner layer of osteocytes.

(v) **Endosteum** lines the **marrow cavity** or the central space.

(vi) The **marrow cavity** is narrow and single in compact bone and is filled with cellular elements and blood vessels. It is called bone marrow and is formed of reticular connective tissue. In compact bones the bone marrow is rich in adipose cells and is called yellow **bone marrow**.

(b) **Structure of spongy bone :** Spongy bone occurs in deeper central parts of bone. It is cancellous without Haversian system. The marrow cavities are many and irregularly arranged. These cavities contain red bone marrow, which produces R.B.C. The bony substance contains large slender spicules called **trabeculae.** Each trabecula consists of many irregularly arranged lamellae with lacunae in between.

Origin and Development of Bone

The bones may develop either by replacing the preexisting embryonic cartilage or by direct ossification in the mesenchyme tissue. The bones formed by the ossification of cartilage are called **replacing bones** or **cartilage bones**, while those which develop in the mesenchyme are called **membrane bones or investing bones.**

THE BLOOD

Blood is red coloured fluid tissue. It is salty in taste and slightly alkaline in nature (pH 7.3 - 7.5). It is heavier than water (specific gravity 1.03-1.05) and viscous. In human beings it forms 7% of the body weight (about 5 litres). Blood is a complex transport medium. It performs vital pick up and delivery services for the body. It is formed of

1. Fluid matrix- **plasma**
2. Formed elements or blood cells - **Corpuscles.**

1. Plasma

Plasma is stew-coloured fluid, about 60% of the total blood or about 5% of body weight. It contains.

Table 3.5: Difference Between Bone and Cartilage

S.No.	Bone	Cartilage
1.	Matrix is composed of tough inflexible material, called ossein	Matrix is composed of a firm, but flexible material, called chondrin.
2.	Matrix is impregnated with salts, chiefly calcium phosphate and carbonate.	Matrix is impregnated with calcium salts only in calcified cartilage.
3.	Matrix occurs in concentric lamellae.	Matrix occurs in a homogeneous mass.
4.	Matrix contains fibres, but these are indistinguishable.	Matrix may contain fibres, which may be distinguishable or not.
5.	Bone-cells (osteocytes) lie in lacunae singly.	Cartilage-cells (chondriocytes) lie in lacunae singly or in groups of two or four.
6.	Osteocytes are irregular and give off branching processes.	Chondriocytes are oval and devoid of processes.
7.	Lacunae send out canaliculi for processes of bone-cells.	Lacunae lack canaliculi.
8.	There are outer and inner layers of special bone-forming cells, the osteoblasts that produce new osteocytes, which secrete new lamellae of matrix.	There are no special cartilage forming cells. Cartilage grows by division of chondrioblasts.
9.	Bone is surrounded by a tough sheath, called *periosteum.*	Cartilage is surrounded by a firm sheath, called prichondrium.

A. Water - 90%

B. Inorganic ions constitute about 0.9% of plasma. These are chlorides, bicarbonates, phosphates and sulphates of sodium, potassium, calcium and magnesium. Chlorides and carbonates of sodium are most abundant.

C. Organic compounds are :

1. **Plasma proteins or serum proteins.** These are about 6.8% of plasma. These contribute to maintain blood viscosity, blood osmotic pressure, and blood volume. These are

(i) **Serum globulin** are 38% of the total serum proteins. These help in osmoregulation, transport of proteins and other substances and form an essential part of immunity system (-**gamma globulins** or **immunoglobulins-** *IG*. These act as antibodies and destroy toxic substances, viruses and bacteria.

(ii) **Serum albumins** are 55% of total serum

pressure of blood by retaining water.

A fall in plasma proteins leads to the escape of excessive volumes of water from blood to tissue. In persons suffering from protein deficiancy this causes swelling of feet (Oedema) due to accumulation of fluid.

2. **Nutrients** dissolved in plasma are glucose, fats, fatty acids, phospholipids, cholesterol, vitamins, amino acids etc. on their way to tissues for storage or to the cells for utilization.
   Cholesterol has tendency to be deposited in the walls of blood vessels of certain individuals, a condition called **atherosclerosis**.

3. **Excretory substances** are ammonia, urea, uric-acid, creatine and creatinine etc.

4. **Hormones, enzymes, antigens** and **antibodies** are also present in plasma.

5. **Gases :** Carbon-dioxide, oxygen and nitrogen are dissolved in plasma.

EXTRACELLULAR FLUID - ECF

RED BLOOD CORPUSCLE

LYMPHOCYTES

MONOCYTE

NEUTROPHIL

EOSINOPHIL

BSOPHIL
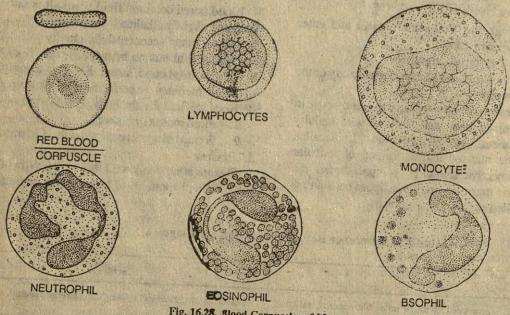
Fig. 16.25. Blood Corpuscles of Man.

proteins. These contribute to the osmotic pressure of plasma.

(iii) **Fibrinogen and prothrombin** are about 7%. these are essential for blood clotting.

FUNCTIONS OF PLASMA PROTEINS

(i). Plasma proteins form source of proteins for tissue cells. Tissue cells form their cellular proteins from these plasma proteins.

(ii). Albumin and globulin maintain osmotic

Fluid outside the cells is called extracellular fluid. In a normal adult man its total volume is about 15 litres. It has about 45% of the total body water, the remaining 50% water occurs in the cells as extracellular fluid.

Function of Blood Plasma

(i) **Transport of food** : Plasma transports digested food to different organs and tissues of the body.

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(ii) **Removal of excretory substances** : Waste substances from the tissues are removed and carried to the kidneys for elimination.

(iii) **Disposal of CO_2** : Major portion of CO_2 from the tissues is removed by plasma, where it remains dissolved in the form of bicarbonates.

(iv) **Transport of oxygen** : Certain percentage of O_2 is also transported by plasma. Even the oxygen which is bounded by the red blood cells is first dissolved in the plasma before reaching the cells.

(v) **Distribution of hormones** : The secretions of various endocrine glands are transported by plasma.

(vi) **Distribution of vitamins**.

(vii) **Regulation of water balance** : Plasma supplies water to different tissues and removes excess of water formed during metabolic processes.

(viii) **Osmotic balance** : Plasma proteins and minerals in the plasma exert osmotic pressure and maintain blood pressure. These also act as acid-base buffers and maintain **blood pH**.

(ix) **Protection against diseases** : Immuno-globulins of plasma act as antibodies and neutralize the harmful effects of foreign agents. These are responsible for **body immunity**.

(x) **Regulation of body temperature** : Blood plasma regulates the body temperature by transporting heat from the deeply seated heat producing organs to peripheral parts of the body for dissipation.

(xi) **Blood clotting or coagulation** : The plasma proteins fibrinogen, prothrombin and some other blood-clotting factors are present in the plasma. In case of injury, these help in the clotting and blood prevent blood loss.

(xii) **Lymph formation** : The lymph is filtered plasma.

2. Blood Corpuscles

Suspended in the plasma are found following cellular element :

1. Erythrocytes,
2. Leucocytes,
3. Blood-platelets.

1. Erythrocytes (Red blood corpuscles—RBCs)

These cells contain haemoglobin and help in transport of oxygen and to some extent CO_2. These are found in all vertebrates. In Fishes, amphibians, reptiles and birds *RBCs* are large, oval and biconvex **nucleated** cells. (a) **Amphibian erythrocytes are largest** measuring about $35\mu \times 16\mu$. (b) **Mammalian RBCs are smallest, nucleated** and roughly circular and biconcave. When mature these are without nuclus, Golgi body, ER. mitochondria, ribosomes and centrosome. **Musk dear has smallest RBC amongst mammals** and in camels and Ilama RBCs are oval. (c) **Human erythrocytes** have a diameter approximately 7.7μ and are $1-2\mu$ thick. **Normal erythrocyte count** is

(i) **Man**—5 to 5.5 million per cubic millimeter of blood.

(ii) **Woman**—4.5 to 4.8 million per cubic millimeter of blood.

The number of RBCs is more in infants and in persons living on hills. Increase in the normal RBC count is **polycythemia** and decrease in the number of RBCs is **anemia**.

Rouleaux Formation - Because of great surface tension, RBCs tend to adhere together by their concave surface like stacks or piles of coins. This is called **Rouleaux formation**.

Respiratory Pigment - Haemoglobin

The cytoplasm of each RBC is packed with about $26 \frac{1}{2}$ crores molecules of **haemoglobin**. Haemoglobin is an iron containing conjugated protein like myoglobin, cytochromes and chlorophyll etc. Its imperical formula is $C_{3032}H_{4816}O_{872}N_{780}S_8Fe_4$. In haemoglobin an iron compound - **haem** is conjugated to four molecules of protein, **globulin**. Haem is a Fe^{++} porphyrin complex with ring structure similar to chlorophyll (In chlorophyll central atom of porphyrin ring is magnesium instead of iron).
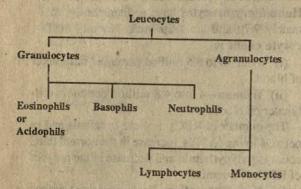
Functions : 1. The erythrocytes are **oxygen carriers**. In regions of higher O_2 concentration **haemoglobin combines with O_2** and forms **oxyhaemoglobin** which is a temporary compound and may carry four molecules of oxygen, loosely bound to its four Fe^{++} ions. In the regions of low oxygen concentration oxyhaemoglobin breaks off liberating free oxygen which is made available to

tissues for respiration. 2. RBCs also help in transport of CO_2 from tissues into the lungs.

2. Leucocytes (White Blood Corpuscles—WBCs)

White blood corpuscles are nucleated amoeboid cells which number 5000 to 9000 per cubic millimeter of blood. Their count is higher in children and also during pathological conditions. The increase in number of leucocytes is called **leucocytosis** and a decrease is called **Leucopenia**. Leucocytes exhibit **phagocytosis** and **amoeboid movement**. These are described as mobile force of body and form the defence system.

Types of Leucocytes

Leucocytes
- Granulocytes
  - Eosinophils or Acidophils
  - Basophils
  - Neutrophils
- Agranulocytes
  - Lymphocytes
  - Monocytes

(A) Granulocytes - Their cytoplasm contains **irregular lobulated nucleus** and different types of granules. These are called **polymorphonuclear leucocytes**. Based on the nature of granules, these may be:

(1) Acidophils or Eosinophils - These have **bilobed nucleus**, the two lobes being connected by isthmus. The **granules** are rounded, coarse and highly refractile with affinity for acidic dyes (eosin). Increase in the number of eosinophils in blood is called **eosinophilia** and is due to parasitic infestation. Their number varies from 70 - 300 per cc.

Function - Eosinophils engulf particles which are formed by antigen-antibody reaction.

(2) Basophils - These have elongated and **S-shaped nucleus** with two or more indistinct lobes. The granules are few, large and spherical with affinity for basic dyes. These are 35 - 150 per cc blood.

Function - Basophils are amoeboid and ingest small particles, like carbon. These contain heparin histamine and Serotonin. These represent mast cells of connective tissue.

(3) Neutrophils or Heterophils - These have **highly polymorphic nucleus** with 3 to 5 lobes. The cytoplasm is differentiated into nongranular **peripheral layer** and granular inner mass, where **fine inconspicuous granules** are closely packed. These absorb both acidic and alkaline dyes. these are 4000 - 5000 per CC blood.

Functions - Neutrophils are most numerous and physiologically most important. These protect the body against invasion of bacteria. These can come out through the capillary wall into the infected area and engulf the micro-organisms by phagocytosis.

(B) Agranulocytes Their cytoplasm is homogeneous **without granules** or with a few azurophilic granules. Their nucleus is spherical or kidney-shaped. These comprise about 25% of the total leucocytes. These are of two types-.

(i) **Lymphocytes** are small blood cells with relatively large **spherical nucleus** surrounded by a thin layer of homogeneous and basophilic cytoplasm. These constitute 20-25% of the total leucocytes (*i.e.* 1500-2500 per cc of blood). These usually migrate through the wall of blood capillaries into the connective tissue (**diapedesis**).

Functions - (i) **Immunity** - Lymphocytes produce serum globulins (β and γ globulins) which are associated with antibody and antitoxin formation.

(ii) **Wound healing** - These contribute to scar formation after injury and help in healing of wound.

(iii) **Show immunological reactions** during tissue plantation.

(ii) **Monocytes** are large-sized agranulocytes with a small **oval** or **kidney-shaped nucleus** and large amount of cytoplasm. The nucleus is eccentric in position. These constitute 3.8% (i.e. 200-700 per cc of blood) and measure 9-12 μ in diameter. These can also leave blood capillaries and develop into **macophages**.

Functions - (i) Monocytes ingest micro-organisms and other foreign bodies that may enter the tissue.

(ii) These are scavengers of dead cells and remove dead and damaged cells.

3. Blood Platelets

These are small (2-4 μ in diameter), oval, rounded or biconvex discs-like. which appear spindle-shaped in profile. These have granular cytoplasm but no nucleus.These contain a contractile protein - **thrombosthinin** similar to actomysin. The blood platelets are regarded to be fragments of **megakaryocytes**, the precursors to white cells found in bone marrow. These play an important role in blood coagulation.

4. Thrombocytes (= spindle cells)

These occur in all other vertebrates, than mammals. These are spindle - shaped cells with spherical or oval nucleus and granular cytoplasm. They function like mammalian platelets.

ALLERGY

Certain foods and drugs act as allergens in some persons and produce allergic reactions but fail to do so in nonallergic persons. Allergic persons have a tendency to manufacture antibodies against mild antigens (called **allergens**). When allergen combines with antibody, it stimulates mast cells to release excessive amount of inflammation causing substances, like **histamines** and **serotonin**. These substances cause extensive dilation of blood vessels, increased permeability of capillaries, excudation of fluid in tissues, spasm, inflammation of bronchial and intestinal muscles, redness of nose, sneezing, watering of eyes etc. This is called **allergy** or **anaphylaxis**. Allergy may cause **asthma, skin irritation** or nasal discharge. **Systemic anaphylaxis** is acute allergy to some specific drugs and may even be fatal.

GLUCOSE

Blood sugar is **glucose**. It occurs in plasma and also in erythrocytes in similar concentration. Normal blood sugar level is 80-100 mg per 100 ml. 12 hours after meal. Its concentrations is highest 1- 1/2 hours after a carbohydrate - rich meal and is about 180 mg per 100 ml. Fasting sugar level is about 60 mg or below. If blood sugar level exceeds 180 mg per 100 ml. it appears in the blood. This condition is described as **diabetes**. **Hyperglycemia** indicates blood glucose level above 160 mg., while **hypoglycemia** indicates blood sugar level below 80 mg.

CHOLESTEROL

Cholesterol level in human blood normally ranges from 50 to 180 mg. per 100 ml. of plasma. It is supplied to tissue cells where it is used for the synthesis of membrane lipids, Vitamin. D, steroid hormones and bile salts. Eating of saturated fats such as butter, ghee, vanaspati and margarine increases cholesterol level in blood, because these are rich in saturated fatty acids. Increased blood cholesterol may lead to blocking heart vessel. Causing heart trouble.

HAEMATOCRIT VALUE

Haematocrit value or the **packed cell volume** is the relative volume of erythrocytes in relation to percentage of total blood volume. It is determined as follows —

Blood sample is collected in a syringe and is rendered noncoagulable by adding anticoagulant - potassium or sodium oxalate. It is then centrifuged in a centrifuge tube or haematocrit tube at 3000 resolutions per minute. Due to centrifugal force, erythrocytes sediment at the bottom of centrifuge tube and form a solid, red bottom layer. The plasma forms a clear straw coloured fluid layer above. Leucocytes form a thin buff-layer.

The haematocrit value of normal person is 45 percent of blood volume.

Erythrocyte Sedimentation Rate - ESR

ESR is the sedimentation rate of erythrocytes. It is determined as follows.

Blood sample is collected and made noncoagulable by adding potassium oxalate. This oxalated blood is kept in long narrow graduated Wintrob's tube. It is left undisturbed for about 30 minutes or more. RBCs begin to sediment slowly from blood plasma due to gravity. Plasma forms a clear layer above them.

ESR for normal blood is — A higher ESR indicates diseases due to abnormal ratio of albumin and globulin in plasma. This value is used as a diagnostic value for several diseases including tuberculosis.

Life Span of Blood Corpuscles
1. **R.B.Cs** - 120 days in man and other mammals.
2. **Granulocytes** - 1-4 days.
3. **Agranulocytes** - Some days to few months.
4. **Blood platelets** - about 10 days.

Disposal of Worn out Corpuscles

Due to short life span about 1% of RBCs and 30% of WBCs are destroyed every day. Spleen, liver and bone marrow play major role in the removal of worn out and aged RBCs. Spleen is referred to as **graveyard of RBCs**. Macrophages and reticulo endothelial cells of blood capillaries phagocytize worn out RBCs. Their haemoglobin is degraded to **globin** and **haem**. Haem is released in blood. Iron of haem from blood is utilized in the synthesis of fresh haemoglobin in the red bone marrow. The remaining part of haem from the blood is picked up by hepatic cells and degraded into bile pigment, **bilirubin**.

When excess of bilirubin gets deposited under the skin, it becomes yellowish and causes disease **jaundice**.

WBCs enter the connective tissues to combat invading agents and toxins and are destroyed in the defence reactions.

Haemopoisis
(Production of Blood Corpuscles)

The short-lived blood corpuscles are always kept at a constant number in the blood by the continuous addition of new cells. The blood cells are regenerated only within the lymphatic and myeloid tissues. These are known as **haemopoietic tissue** and the process of their formation as **haemopoiesis**. In frog spleen, liver and lymph nodes are the main haemopoietic organs. In mammalian embryo, haemopoiesis occurs in yolk sac, liver, bone marrow and thymus. In adult, red blood corpuscles are formed in the red bone marrow in long bones. Lymphocytes are formed in thymus, spleen and lymph nodes, tonsils etc.

The haemopoietic tissue contains the precursor cells of all blood elements. These are the *primitive* **reticular cells**, called **haemocytoblast**. The

haemocytoblast of bone marrow are termed as myeloblasts.

Formation of Erythrocytes (Erythropoiesis)
RBC are formed from myoloid haemopoietic tissue. The mechanism involves following steps.

Erythroblasts are the precursors of RBCs these have a rounded nucleus and basophilic cytoplasm. during maturation, these undergo several mitotic divisions, everytime gaining haemoglobin (**Normoblasts**). Finally, these transform into mature RBCs by losing nucleus, ER, Golgi, ribosomes etc. Spleen acts as a reservoir for mature RBCs by losing nucleus, ER, golgi, ribosomes etc. Spleen acts as a reservoir for mature RBCs, formed in excess of body's immediate requirement.

PROCESS OF COAGULATION OF BLOOD

Blood, whenever comes out of the vessels, quickly changes from a fluid state into a thick jelly-like material. This is known as **clot** and the process as separation of clot from the plasma (the **serum**) is known as **clotting** or **coagulation**.

Mechanism of Coagulation

The process of clotting involves the conversion of soluble blood protein, the **fibrinogen** (which is normally dissolved in plasma) into insoluble fibrous protein **fibrin** (which is in the form of long delicate fibres). But due to the involvement of a variety of factors of different nature the process is much complicated and can be separated under following steps:

Step 1. **Liberation of thromboplastin or origin of thromboplastic activity in blood** - In the circulating blood thromboplastin is present. Thromboplastic activity arises only at the time of clotting by the combination of certain factors. These factors are : a *phospholipid* furnished by rupturing of the platelets, Ca^{++} ions and antihemophilic factor.

Step 2. **Conversion of prothrombin into thrombin** - The prothrombin is the inactive form of the enzyme thrombin which is essential for blood clotting. In presence of Ca^{++} ions the accelerator globulin *i.e.* the prothrombin is converted into thrombin by thromboplastic activity of thromboplastin.

STEM CELLS
or
MYELOBLASTS → Proerythroblasts → Erythroblasts → Normoblasts → Erythrocytes
(Red bone marrow)

Ruptured blood platelets
↓
Thromboplastic activity
↓
Thromboplastin
↓
Prothrombin ————————→ Thrombin

Ca++ & Ac-globin

Fibrinogen ————→ Fibrin ————→ Fibrin
(soluble) Fibrin stabilizing (insoluble) factors and Ca++

Fig. 16.29 Clotting of blood.

Step 3. **Conversion of fibrinogen into fibrin** - Thrombin is proteolytic enzyme, whose action converts the soluble plasma protein, fibrinogen,

slowly as to put them in danger of fatal haemorrhage. This is known as *'bleeder's disease'* or **hemophilia**. Persons with hemophilia fail to survive or always have the danger of being excessively bled.

Composition of Lymph

The lymph is a transparent, slightly yellowish liquid of alkaline nature found in lymphatic vessels. Lymph and plasma are nearly identical in composition except that the average protein concentration is comparatively less. It caries some oxygen and the final products of digestion to be supplied to the tissue fluid.

ARNOLD and MENDEL have given the comparative composition of plasma and lymph from the thoracic duct as shown in table given below :

S.No.	Substance	Plasma	Lymph
1.	Protein	6.18 mg/100 ml	3.32 mg/100 ml
2.	Nonprotein nitrogen	32.6 mg/100 ml	35.2 mg/100 ml
3.	Sugar	112 mg/100 ml	107 mg/100 ml
4.	Chlorides	660 mg/100 ml	711 mg/100 ml
5.	Inorganic constituents	4.8 mg/100 ml	5.9 mg/100 ml
6.	Calcium	10.8 mg/100 ml	9.7 mg/100 ml

into insoluble protein fibrin. According to recent view fibrin molecules initially obtained are soluble but in presence of cation and the fibrin-stabilizing factor (F - XIII), it is converted into insoluble fine threads which separate from the blood plasma and settle down in the form of a fibrous net.

Step 4. **Role of blood platelets** - The blood platelets are presumed to contain thromboplastin. It is liberated when blood platelets rupture. The rupture of blood platelets occurs when capillaries or blood vessels are damaged and blood flows out. This also liberates a number of other factors which activate the process of clotting.

Significance of Coagulation

Clotting or coagulation of blood is very essential phenomenon in the life of an organism. If any blood vessel or capillary is ruptured, its blood immediately starts oozing out. **Coagulation** prevents excessive hemorrhage from small wounds and this helps in retaining the blood inside the body. Its importance is realized by the study of those cases, where blood fails to clot or it clots so

The lymph contains a number of W.B.Cs. mostly lymphocytes. It also contains **prothrombin** and is, therefore, capable of clotting.

The composition of lymph varies slightly from place to place, and from time to time. For example, lymph from the thoracic duct is rich in fats after absorption of fats from small intestine.

MUSCULAR TISSUE

Muscular tissue is formed of greatly elongated and highly contractile muscle cells which are called **muscle fibres**. These are placed together in the connective tissue to form bundles. The intercellular substance or matrix is absent. Muscles are responsible for all outward manifestations of life. Three types of muscular tissues have been distinguished :

1. Smooth muscles or unstriated muscles.
2. Striped muscles or striated muscles.
3. Cardiac muscles.

1. Smooth or Unstriated Muscles

Location

These are also known as plain or smooth or

nonskeletal muscles. These are found in close asso-
ciation with the ordinary connective tissue and
form contractile portion of the **wall of digestive
tract** and of the **urinary** and **genital ducts.**

Structure

The muscle cell or the muscle fibre is elongated
and spindle-shaped and occasionally branched at
the ends. It reaches the length of 0.2 - 0.5 mm. and
thickness of 6μ. It consists of a long cigar-shaped
nucleus present in the widest portion of the cell-
body. The cytoplasm is homogeneous and unmodi-
fied with little or no granules. It is known as
sarcoplasm. In it are found numerous fine contrac-
tile threads, the **myofibrils,** which lie parallel to
the long axis of the cell. The fibrils are highly
contractile and are formed of **myosin.** The cyto-
plasm is bounded externally by a thin
sarcolemma.
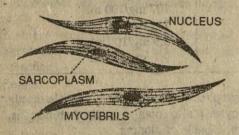
Fig. 16.30 Unstriated muscles fibres.

Functions

The smooth muscle fibres may lie isolated or in
bundles. Usually a number of muscle fibres are
united together by connective tissue into a thin and
flat band and a number of such bands are bound
together into cylindrical muscle bundles. The un-
striated muscles are never under the control of
will, hence they are also known as **involuntary
muscles.** Their function is to bring about opening
and closing of cavities of tubes. The contraction is
slow but prolonged.
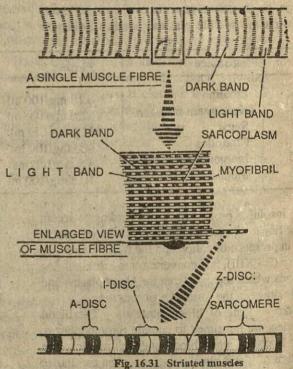
2. Striped or straited muscles
Location

The striated muscles form the flesh of the body

and are mostly attached to the skeleton. Hence they
are also known as **skeletal muscles.**

Structure

Each muscle cell is an elongated, straight and
unbranched cylindrical fibre, 10 to 100 μ in thick-
ness and upto 4 cm in length. It consists of a thin
outer limiting membrane, the **sarcolemma** which
encloses a coenocytic cytoplasm, known as **sarco-
plasm.** The nuclei are peripheral in position. In the
sarcoplasm lie embedded large number of **myofi-
brils** or **sarcostyles.** tightly packed in parallel
bundles and are separated by thin sheets of cyto-
plasm.

Fig. 16.31 Striated muscles

Myofibril

Each myofibril is about 1 μm in diameter. It is
differentiated into alternate segments or bands of
lights and dark colour.

1. The **light bands** are nonrefrective under po-
larised light and are known as **isotropic bands** or **I-
bands.** Each is bisected at its midpoint by a thin
dark line, the **Z-band** or **Krause's membrane.**
The portion of myofibrils between adjacent Z-
bands is known as **sarcomere** and it represents the
contractile unit. On both sides of Z-line, is a still

darker – N-line.

2. The **dark bands** are doubly refractive and are known as **anisotropic bands** or **A-bands**. Each A-band is also bisected at the midpoint by a thin paler line. It is known as **Hensen's line** or **H-band**. A narrow dark line, **M-line** or **M band** passes through the middle of H-band. Myosin filaments are thickened at M-bands.

Ultrastructure of Myofibril

Each myofibril is composed of serially repeated sarcomeres (the unit of contraction). Separated by Z-discs. Each sarcomere is formed of two types of myofilaments :-

(i) Thick - **myosin myofilaments** and

(ii) Thin - **actin myofilaments**

1. **Myosin filaments** - The thick myosin filaments are confined all along the length of A-bands and are formed of protein **myosin**. these are about 1.5 μ in length and slightly thicker in middle.

2. **Actin myofilaments** - Within each sarcomere, the actin filaments are present in the I-bands. These re attached to the Z-band at one end. Their free ends extend through A-bands towards H-disc and interdigitate with the myosin filaments. The H-zone of A bands is without actin filaments. Each thin filament contains proteins **actin, tropomyosin** and **troponin.**

The I-bands represent those regions of actin filaments, which do not overlap with myosin. the H-bands are the middle region of A bands (myosin) which are without actin filaments. At M-band region, which lies in the middle of H-band, the myosin filaments are interconnected by fine strands.

Muscle Contraction

The process of muscle contraction is intimately associated with protein filaments of the myofibrils. the sarcomere is the unit of contractility and is represented by the region between successive Z-discs. During muscle contraction the thin actin filaments slide farther and farther among thick myosin filaments and result in the contraction of sarcomere. The contraction of sarcomeres causes the muscle to shorten in length. During contraction I-bands shorten and Z-discs disappear, but the length of A-bands remains constant throughout the process.

Sliding Filament Theory of Muscle Contraction

This theory was put forward by HANSON and HUXLEY (1865). During muscle contraction, the thin actin filaments slide over the thick myosin filaments towards the centre of sarcomere into the A-band and H-band.
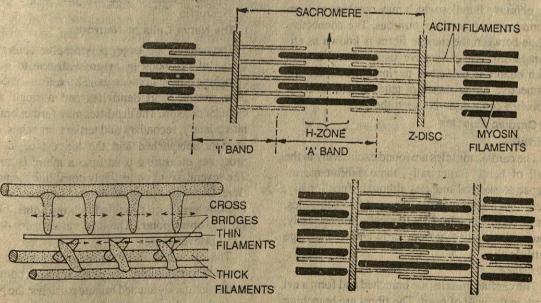
Fig. 16.33 Position of cross bridges between myosin and actin filaments during sliding.

Fig. 16.34 : Physical changes during muscle contraction.
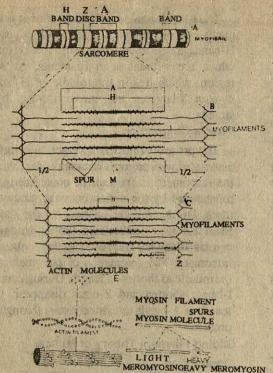
Fig. 16.35 Diagrammatic representation of action of cross bridges.

Fig. 16.36 Cardiac muscles.

The muscle fibres of striated muscles occur in the bundles which are formed of parallel muscle fibres held together by connective tissue. These are **primary** bundles which may combine to form **secondary** and **tertiary bundles.** The connective tissue between the muscle fibres is known as **endomysium,** the connective tissue-sheath around each bundle is termed as **perimysium,** while the connective tissue-sheath of tendons and, thus establishes connection between the two.

3. Cardiac Muscles

Location

The cardiac muscles are found exclusively in the wall of heart. Structurally, these exhibit resemblance to skeletal muscles although, functionally, these are homologous to the unstriated muscles. These contract rapidly, rhythmically and tirelessly, contracting endlessly from early embroynic stage until death.

Structure

The cardiac muscles are branched and form a net work in the wall of heart. The fibres are branching and anastomosing separated by loose connective

tissue richly supplied with blood capillaries. The sercolemma is more abundant and the myofibrils are comparatively less in number. These are uninucleate with centrally located nucleus. The myofibrils in structure resemble to those of skeletal muscle.

NERVOUS TISSUE

The nervous tissue is specialized for receiving and transmitting stimuli. It consists of :

1. Nerve cells or neurons, 2. Nerve fibres 3. Neuroglia.

1. The Nerve Cells or Neurons

The neurons are large, polymorphic cells consisting of cell-body or **cyton** with one to many branching fibrous processes. These usually comprise several short **dendrites** and a single axis cylinder or **axon.** The dendrites may further branch into primary, secondary and tertiary branches. The axon is unbranched and the longest of all the processes measuring even upto a metré or more. The several axons collectively constitute the nerve fibre. Depending upon the number of processes the neurons have been classified into **unipolar, bipolar** and **multipolar.** The size varies from 4μ to 135μ or even more.

The cyton consists of large oval nucleus surrounded by cytoplasm, the **perikaryon.** It contains numerous darkly stained minute particles, the **Nissl granules** and several cytoplasmic strands, the **neurofibrillae.** The Nissl granules are either excretory
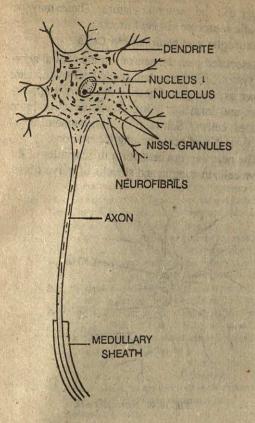
Fig. 16.37 Structure of a neuron.

neurons and carry them to the cell-body. Thus these are the chief respective organelles of neuron. The axon on the other hand receives nervous excitations from its own cell body and transmits them either to the dendrites of other neurons or to effector cells. The terminal end of each axon divides into fine branches which are known as **telodendria.** These might end into tiny end bulbs. The association between the telondria and dendrites isknown as **synapse.** At the synapse the plasma membrane of the two remains in contact with slight space in between, the cytoplasmic continuity is lacking.

2. Nerve Fibres

The nerve fibre is the axis cylinder or axon of a neuron surrounded by its enveloping sheath. So, each nerve fibre consists ofa central core of *axon*, a drawn0out portion of neuroplasm which os now known as **axoplasm,** and the encircling plasma membrane, called **axilemma** or **neurilemma.** Such fibres are known as **unmyelinated nerve fibres.** Many nerve fibres possess an additional covering. These fibres are placed between the axis cylinder and neurolemma, and are known as myelinated nerve fibre. These are glistening white in appearance and contain high contents of lipids. The myelin sheath or medullary sheath is regarded as an

or nutritive in function, while the neurofibrillae help in the transmission of nerve impulses to and from the cell body. Some of the neurofibrillae extend into the process of cell body.

The dendrites through their synapses with the axon endings receive nervous impulses from other
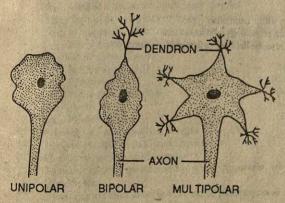
Fig. 16.38 Different types of neurons.
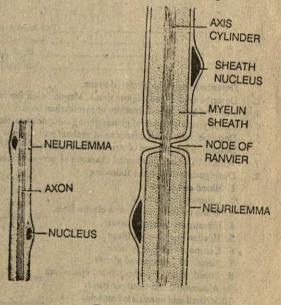
Fig. 16.39 Nerve Fibres
A - Nonmedullated
B - Medullated

insulating covering and is said to increase the speed of conduction. Immediately underneath the neurilemma is a thin sheath of cytoplasm containing nuclei. These are known as either *sheath nuclei* or *nuclei of Schwann cells* and are concerned with the formation of neurilemma.

The Myelin-sheath is not continuous along the entire length of cylinder but is interrupted at intervals of about 1 mm. As a result, the neurilemma enters deep at these points and lies in contact with the axon. The nerve fibre, therefore, appears constricted and each constriction is known as **node of Raniver**. These nodes are said to provide place for the diffusion of lymph laden with nutrient material. The medullated nerve fibres form the cranial and spinal nerves, while the non-medullated nerve fibres occur in the autonomic nervous system.

The nerve fibres are of two types :

(i) **Afferent nerve fibres** - These carry impules form the receptor organs to the brain and spinal cord and are sensory in nature. These may be **somatic sensory** or **visceral sensory**, receiving sensation from the external or internal environment of the body.

(ii) **Efferent nerve fibres** - These carry impulses from the brain or spinal cord to the effector organs and are motor in nature. These may be **somatic motor** or **visceral motor**.

3. Neuroglia and Neurilemma Cells

Associated with the neurons in the central nervous system are seen certain special cells which are known as neuroglia. These have different appearances and form the lining of ventricles or brain cavities, cells of Schwann of the peripheral nervous system, and occur among the neurons.

The **neurilemma cells** form the capsules of the nerve cells in ganglia and sheaths of nerve fibres.
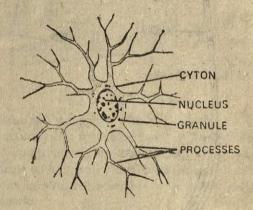
Fig. 16.40 Neuroglia cell.

QUESTIONS

1. Describe in brief the epithelial tissue.
2. Describe areolar and adipose tissue. Mention their functions.
3. Describe histological structure of mammalian bone.
4. Classify various types of glands giving suitable examples.
5. Describe characteristic features of skeletal muscle, how they differ from other types.
6. Describe ultrastructure of striated muscle fibre with a note on physiology of contraction.
7. What is basic or fundamental character of nervous tissue. Describe detailed structure of a neuron.
8. Distinguish between the following:
   1. Blood and lymph
   2. Ligament and tendon
   3. White collagen and yellow elastin fibres
   4. Fibrous and reticular tissue
   5. Hyaline and fibro cartilage
   6. Compact and spongy bone
   7. Simple and compound glands
   8. Stratified and pseudostratified epithelium
   9. Anisotropic and isotropic bands
   10. Striated and nonstriated muscles
   11. Actin and myosin
   12. Plasma and serum
   13. Granulocyles and agranulocytes

14. Exocrine and endocrine glands
15. Nerve fibre and muscle fibre
16. Neuron and neuroglia

9. Match the following:

Column A	Column B
(i) Canaliculi	(a) a protein present in connective tissue, secreted by fibroblasts
(ii) Chondrocytes	(b) Undifferentiated cells on the outer walls of capillaries
(iii) Cilial cells	(c) Cartilage cells that secrete matrix of cartilage
(iv) Myofibrils	(d) Scavenger cells that clean up cellular debris
(v) Platelets	(e) Ground substance
(vi) Macrophages	(f) Connective tissue cells that produce and secrete proteins and other components of matrix
(vii) Fibroblasts	(g) Tiny channels in bone enclosing fine processes of bone cells
(viii) Collagen	(h) Supporting cells present in nervous tissue
(ix) Matrix	(i) Long, contracted fibres
(x) Pericytes	(j) Cell fragments that help in blood clotting

10. How do erythrocytes transport oxygen and carbon dioxide in food?
11. Name two important plasma proteins and discuss their functions.
12. Describe process of clotting of blood.
13. What is anticoagulin? What substances are used as anticoagulants.
14. Describe role of Y-globulins, heparin, seratonin.
15. Name the sheath that surrounds the axon of medullated nerve fibre.
16. Name the specific cell for each showing the undermentioned characteristics :
    (*i*)   The dead cells with sieve plates at the ends.
    (*ii*) The cells having living cytoplasm, thick primary wall with special thickenings on the corners.
    (*iii*) Long fibre-like, highly contractile cells with cross stripes of light and dark bands.
    (*iv*) Long cylindrical cells without nucleus and cytoplasm but having thick lignified walls and without end walls.
    (*v*)   The amoeboid cells with S-shaped nucleus.
17. Which tissue lines the following :
    (*i*) Our cheek   (*ii*) Oesophagus
    (*iii*) Thyroid gland   (*iv*) Intestine.
18. What kind of muscles are involved in the following processes :
    (*i*) Movement of food in the alimentary canal.
    (*ii*) Movement of arm.
    (*iii*) Constriction of anus.
    (*iv*) Movement of eyelid.
19. Name the tissue which has the following structures :
    (*i*) Intercalated disc _____   (*vi*) Schwann cell _____
    (*ii*) Sarcolemma _____   (*vii*) Fibroblasts _____
    (*iii*) Nissal granules _____   (*viii*) A band _____
    (*iv*) Histiocytes _____   (*ix*) Myofibril _____
    (*v*) Haversian system _____
20. State true or false for each of the following statements :
    (*i*)   Tendon is formed of white fibrous tissue.
    (*ii*) Cardiac muscles are involuntary muscles.
    (*iii*) Cells of parenchymatous tissue have thick walls.
    (*iv*) In adipose tissue the nucleus is found in the centre of the cells.
    (*v*)   Blood platelets are formed from macrophages.
21. Give one function of each:
    (*i*)   Sclerenchyma cells   (*ii*) Xylem
    (*iii*) Fibrocytes   (*iv*) Sieve tubes
    (*v*)   White blood corpuscles (*vi*) Tendon
    (*vii*) Histiocytes   (*viii*) Ligament
    (*ix*) Blood platelets   (*x*)   Dendrites
22. What salts are deposited in the matrix of bone ?
23. Give one example of fluid connective tissue.
24. What is the function of sclerenchyma?
25. The matrix of cartilage is formed of a specific protein. What is its name ?
26. Define tissue.
27. Cells which are thick at corners are called parenchyma or sclerenchyma ?
28. Give two differences between blood and lymph.

29. Give two main difference between striated and non-striated muscles.
30. Define the following in not more than two sentences :
    (i) Tissue (ii) Connective tissue
    (iii) Cardiac muscle (iv) Synapse
    (v) Protective tissue (vi) Neuron.
31. Give functions of connective tissue.
32. Give functions of R.B.Cs. How it carries out its function ?
33. Give various functions of W.B.C. in human blood.
34. Give functions of epithelial tissue.
35. Describe different types of white blood corpuscles and their functions.
36. Write functions of lymph.
37. Define tissue. How many types of tissues are found in animals ?
38. Describe the structure of mammalian bone with the help of a labelled diagram.
39. Give an account of different types of connective tissue.
40. **Diagrammatic Questions :**
    1. Draw a labelled Sketch of bone.
    2. Draw a labelled sketch of a neuron.
    3. Draw a labelled sketch adipose tissue.
    4. Draw a labelled sketch of areolar tissue.

Animal Nutrition

NUTRITION

Nutrition (L. nutrine - to nourish) is the process that provides raw materials or **nutrients** needed by the organisms for running and maintaining body machine. The nutrients are used as

(i) **building blocks** for synthesizing new protoplasm needed for growth and repair of body and

(ii) as **energy source** for various body activities.

The major nutrients are three organic compounds – **carbohydrates, proteins and fats.** These are called **macro-nutrients.**

Autotrophic anc Heterotrophic Nutrition

Energy comes to our planet in the form of sunlight. It is trapped by plants, monerans and some proteists during photosynthesis. These initial harvesters of energy are called **autotrophs.**

Animals have no chlorophyll and cannot synthesize their food. They obtain energy from food either directly from plants by eating them or indirectly by eating other animals which eat plants. So animals are described as **heterotrophs** and their mode of feeding as **heterotrophic nutrition.** Heterotrophs can be –

1. **Holozoic** feeding on solid organic matter.
2. **Parasitic** obtain predigested organic food from the host. These may be –
   (i) **Ectoparasitic forms** live on the body of host such as body louse, bed-dug etc.
   (ii) **Endoparasitic forms** live inside the body of the host either inside the cells (**intracellular parasite**), in the tissue fluid or blood (**intercellular parasites**) or in the lumen of body organs e.g. malarial parasite, *Trypanosome,* tapeworm, round worm etc.
3. **Saprozoic** or saprophytic forms absorb dead organic matter in solution through their body surface.

MODES OF ANIMAL NUTRITION

On the basis of food, heterotrophic animals can be:-

1. **Herbivorous** (L. *Herba:* herb ; *Vorare* : to eat). The animals like cow, horse, sheep, cattle etc. which feed exclusively on plants are called **herbivores** or **herbivorous.**

2. **Carnivorous** (L. *Carnis:* flesh). The animals like lions, tigers, dogs, wolves and foxes etc. that kill and prey upon living animals are carnivores or predators.

3. **Omnivorous** (L. *Omnis:* all). Animals like man, cockroaches, crow, pig, etc. feed on both plants and animals. These are called **omnivorous.**

4. **Carrion eaters.** These feed on dead animals and also called **scavengers.** Examples are Hyaena, vultures, kites etc.

5. **Frugvivorous** animals feed on fruits and fruit juices.

6. **Sanguivorous** are blood-sucking animals and

7. **Insectivorous** like frog and toad are insect eating animals.

PROCESS OF NUTRITION

The process of nutrition involves the following steps –

1. **Ingestion.** Taking in of the food (also called feeding).

2. **Digestion.** Breaking down of complex food components into simple soluble substances.

3. **Absorption.** Absorption of digested food by the wall of alimentary canal into the blood.

4. **Assimilation.** Utilization of digested food by different body cells.

5. **Egestion.** Elimination of undigested food residue as faeces.

Ingestion or Feeding Mechanisms in Animals

The mode of feeding depends on the nature of food as follows –

A. Feeding Mechanisms in Liquid feeders
(Fluid Feeders)

The liquid feeders intake food by one of the following methods-

(i) **Diffusion.** Many parasitic protozoans, tapeworms absorb the dissolved organic food through their body surface.

(ii) **Pinocytosis** or **cell drinking**. Substances of high molecular weight which cannot enter the cell by diffusion are taken in by the cells by pinocytosis. Droplets of dissolved food bind to the cell membrane. The cell membrane invaginates forming pinocytic channels. The food droplets pass along these channels. Inside the cell cytoplasm, these are pinched off as **pinocytic vesicles**. These migrate deeper into the cell.
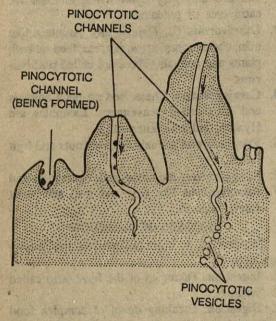
Fig. 17.1 Pinocytosis in Amoeba .

(iii) **Blood sucking** – Leeches, vampire bats and mosquitoes are blood-suckers. Their mouth parts are modified for that purpose.

(iv) Aphids suck sap of plants.

B. *Feeding Mechanisms in Microphagous Animals* (Filter-Feeders)

The food of **microphagous** animals includes organisms suspended in water, such as bacteria, diatoms, protozoans, unicellular algal and plankton Protozoans, sedentary animals like sponges, corals, barnacles and bivalved molluscs and mobile filter feeders baleen whale, tadpoles and mosquito larvae etc. are all **microphagous animals**. These possess filtering devices, such as clusters of pseudopodia, cilia or flagella in protozoans ; flagella in sponges; sheets of mucus in some annelids,

crustaceans and snails.

Paramecium has specialized oral apparatus. The constant lashing movement of cilia of oral groove derives food laiden water current towards the vestibule. From the vestibule fine food particles enter the cytopharynx through cell mouth. At the bottom of cytopharynx these are nipped off in the cytoplasm as a **food vacuole**.
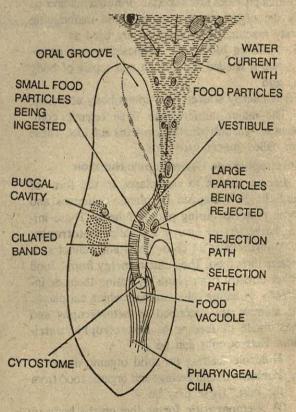
Fig. 17.2 Ingestion in *Paramecium* ,

In **sponges** the water current with food organisms is drawn inside the body by the beating of flagella of collar cells. The food organisms are engulfed by the collar cells at the base of collar (Fig. 2.1).

C. *Feeding in Macrophagous Animals*

Macrophagous animals feed on large plants or animals or their parts.

(i) Simple forms like *Amoeba* has no mouth. Prey is ingested by pseudopodia at any point on the cell surface and is enclosed in the food vacuole.
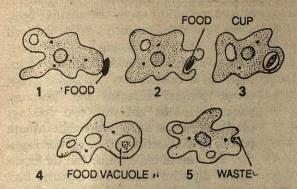
Fig. 17.3   Ingestion of food in Amoeba by pseudopodia.

(ii) Some animals like **Hydra** have tentacles for capturing an ingesting the prey.
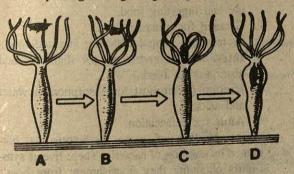
Fig. 17.4 Food capture in *Hydra*.
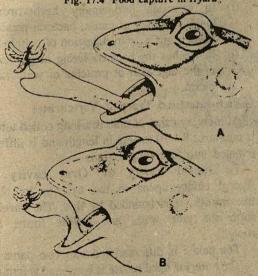
Fig. 17.5 Food capture in Toad.

(iii) **Deposit feeders or detritus feeder** – Burrowing animals like earthworm suck solid organic food along with great quantity of soil. The pharynx helps in swallowing.

(iv) Frogs and toads use their eversible slimy and sticky tongue for capturing insects and worms. They short out the tongue on the prey.

(v) In man and other mammals teeth are specialised for biting, cutting, tearing, chewing and masticating the food. These are –

  (a) **Incisors** mean for biting, and have sharp, flat edges.

  (b) **Canines** are pointed and are adapted for tearing.

  (c) **Premolars** and **molars** for grinding.
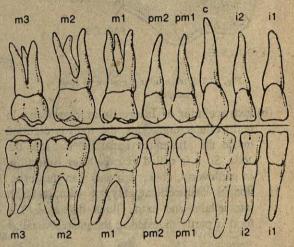
Fig. 17.6. Heterodont teeth of man.

In **carnivores** (dog, lion) canines are large for tearing the flesh of the prey ; whereas in **herbivores** (horse, cow etc.) premolars and molars have high ridges for grinding.

Digestion

Digestion is the process by which complex molecules of food (carbohydrates, proteins and fat) which are insoluble are broken down (hydrolyzed) into simple molecules glucose, amino acids, fatty acids and glycerol so that these can be absorbed by the wall of alimentary canal. It involves a number of physical and chemical processes and is assisted with hydrolytic or **digestive enzymes**.

(a) **Intracellular digestion** – In unicellular

organisms like, *Amoeba* and *Paramecium*, the food is digested inside the **food vacuoles**. The digestive enzymes are secreted in the food vacuoles by the surrounding cytoplasm. This is known as **intracellular digestion**.
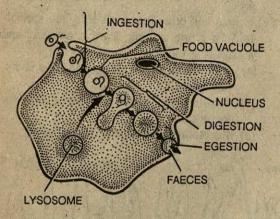
Fig. 17.7 Intracellular digestion of food in *Ameoba*.

(b) **Extracellular or Intercellular digestion** - In multicellular organisms, the food is digested inside the alimentary canal i.e. out-side the cells. So it is called **extracellular digestion**. In earthworm, cockroach and man the digestion is extracellular, **Hydra** exhibits both intracellular and extracellular digestion. The food is partly digested in the **gastrovascular**
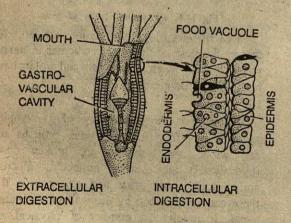
Fig. 17.8 Extracellular and intracellular digestion in *Hydra*.

cavity with the help of enzymes secreted by the gland cells of gastrodermis. The small bits of food are picked up by the nutritive cells, where final digestion occurs inside the food vacuoles. The single opening of gastrovascular cavity serves as both mouth and anus.

(c) **Digestion in Tubular guts** - All animal groups except sponges, cnidarians and flatworms, possess a tubular **gut** with two openings usually situated at the opposite ends. **Mouth** present at the anterior end serves for ingestion and **anus** at the opposite end for expulsion of digestive wastes. The digestive tract exhibits specialized compartments for particular functions. In invertebrates (for example cockroach), the GI tract is differentiated into following parts.

1. **Mouth** and **buccal cavity** for cutting, chewing and ingesting food.
2. **Gizzard** for grinding food.
3. **Stomach** or **crop** for storing ingested food.
4. **Intestine** or **mesenteron** for digestion and absorption of food.
5. **Rectum** or **hindgut** for absorption of water and salts.
6. **Anus** for defaecation.

The hindgut of some herbivores is harboured by colonies of bacteria. These live as **symbionts** obtaining their nourishment from host's digested food and assisting host in the process of digestion. For example ;

(i) In termites and many herbivorous mammals such as cattle, bacteria present in their gut help in digestion of cellulose.
(ii) In leeches the bacteria living in gut help in the digestion of proteins of vertebrate blood.

Gastro-Intestinal Tract of Vertebrates

Alimentary canal of man is a long coiled tube. It measures 8 - 10 meters in length and is differentiated into following regions —

1. **Buccal cavity or Oral cavity** – Buccal cavity opens to the exterior by slit-like **mouth**. It is bounded by **lips**. The **cheeks** form the side walls and **palate** forms its roof.

The palate is differentiated into two parts. The **anterior hard palate** is bony, and is formed

of two maxillae and two palatine bones and it helps in retaining food in the buccal cavity for proper mastication. The **posterior soft palate** is formed of muscles arranged in the form of an arch. It forms a partition between oral cavity and nasopharynx. It helps in directing food towards oesophagus. The opening in the arch leads into the oro-pharynx and is named **fauce.** Suspended from the midpoint of posterior border of the arch is a cone-shaped **uvula.** It hangs down between buccal cavity and pharynx like a curtain. There are two fleshy arches one on either side of uvula and between them is present an almond-shaped **palatine tonsil.**

The buccal cavity is lined with mucous mem-

brane. Present in the buccal cavity are **tongue, teeth** and **tonsils.**

1. **Tongue** – A muscular **tongue** is present on the floor of buccal cavity. It is attached to **the** mandibles and hyoid by muscles and to the floor of buccal cavity by a fold of mucous membrane present mesially on the under-surface of tongue. This fold is called **frenulum.** Skeletal muscles covered with mucous-membrane form the tongue. The gland cells of mucous membrane secrete mucus that keeps tongue moist. Its dorsal surface is marked by a V-shaped furrow, the **sulcus terminalis.** The rough elevations on the surface of tongue are
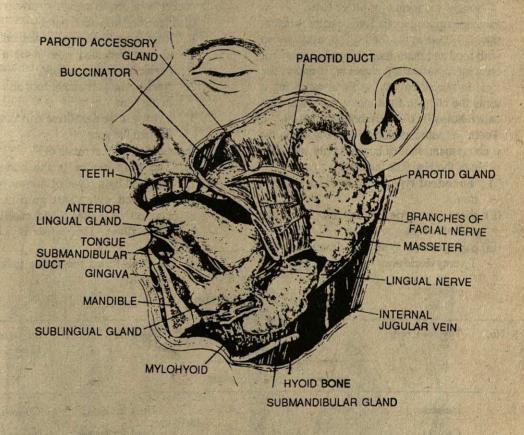
Fig. 17.9 Alimentary canal of man

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lingual papillae. These are of there types—

(i) **Filiform papillae** are thread-like and are distributed over anterior two-third of the tongue.

(ii) **Fungiform papillae** are mushroom-shaped and are more numerous near the edges of tongue.

(iii) **Circumvallate papillae** from an inverted-Vat the posterior part of tongue.

Taste bunds: These are located on the sides of fungiform and circumvallate papillae.

(i) Taste buds located near the tip of tongue taste for **sweet.**

(ii) Those present on the sides taste of **sour** and

(iii) Those located on the posterior part of tongue are meant for **bitter taste.**

Functions of tongue: (i) Tongue helps in ingestion. (ii) It tastes the food (iii) It mixes saliva with food and maes food soft and slippery for chewing. (iv) During chewing, it moves the food in buccal cavity. (v) For swallowing it turns the chewed food into a spherical mass called **bolus** (iv) Tongue helps in speech.

2. **Teeth** – Teeth develop by ossification in the mucous membrane of buccal cavity, along the ridge of the jaw. The teeth are –

(i) **bunodont type** *i.e.* adapted for mastication.

(ii) **thecodont type** *i.e.* are fastened in the sockets of the jaw bones.

(iii) **diphyodont type** i.e. develop twice. Twenty **deciduous** teeth developed in the baby. These are called **baby teeth** or milk teeth. These are replaced later between the age of 6-13 by 32 **permanent teeth.** These include 6 molars in each jaw. Last of these molars are **wisdom teeth.**

(iv) **heterodont** *i.e.* of various shape, size and structure.

See table below

Dental formula– The arrangement of permanent teeth can be represented by dental formula,

$$I^2/_2; C^1/_1; PM^2/_2; M^3/_3$$

or $\dfrac{2, 1, 2, 3}{2, 1, 2, 3} \times 2 = \dfrac{16}{16} = 32$

Structure of tooth– The tooth is placed in a socket or alveolus over the jaw bone. It is distinguished into three parts—

1. **Root** is the basal part embedded in alveolus and separated from it by a vascular **periodontal membrane.**

2. **Neck** is the part above root and enclosed in the gum.

3. **Crown** is the distal free part that projects beyond the gum.

In section a tooth consists of

1. The **pulp cavity** is the central space bounded by a layer of **odontoblast cells** and filled with a soft **pulp** made up of connective tissue, blood capillaries and nerve fibres. The region is sensitive to pain.

2. **Dentine** forms the major part of tooth.

Table - Dentition

S. No.	Type of Teeth	Number Teeth per jaw		Function	Shape of Crow
		Deciduous	Permanent		
1.	Incisors	4	4	Used for biting	Chisel-shaped
2.	Canines	2	2	Used for tearing	Dagger-shaped, conical
3.	Premolars	4	4	Used for grinding	Cusped-crown
4.	Molars	0	6	Used for grinding	Cusped-crown
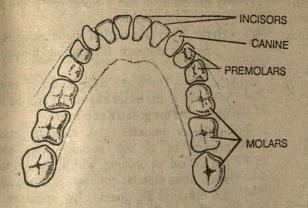
Fig. 17.11   Arrangement of teeth in the upper jaw

Chemically it is similar to bone, being formed of calcium carbonates and phosphates. It is traversed by collagenous fibres and is yellowish in colour.

3. **Enamel** forms the outermost layer of tooth. It lines dentine in the crown and nick region. It is white in colour and is formed of calcium phosphates and carbonates, with enamel rods. It forms cusps of premolars and molars.

Diseases of tooth

1. **Periodontitis** is the inflammation of gums and periodontal membrane.

2. **Pyorrhoea** is caused by the growth of micro organisms in the space between adjacent teeth where food accumulates. The tooth sockets get swollen, roots of teeth become weak and mouth gives a foul smell.

3. **Riggs** disease is caused by *Entamoeba gingivalis*. Its **protelytic** and **cytolysin** enzymes in presences of CO_2 and water act upon tooth enamel and gradually dissolve it forming cavity. The cavity may go deeper into the dentine or upto the pulp cavity. We feel pain when cavity reaches the dentine.

4. **Falling of teeth** in old age is due to accumulation of cholesterol in the root canal through which artery enters the pulp cavity. It closes the opening of pulp cavity and cuts of blood supply and nourishment to dentine and enamel, causing fall of teeth.

5. **Scurvy**, is a gum disease caused by the deficiency of vitamin-C.

3. **Tonsils** - These are two oval patches one on either side in the posterior part of buccal cavity.

(A) INCISOR TOOTH   (B) MOLAR TOOTH
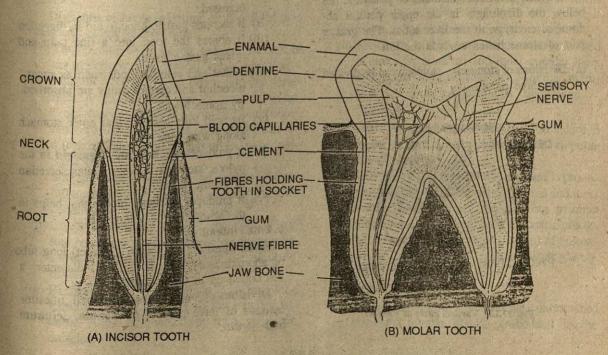
Fig. 17.11 L.S. of an incisor and a molar tooth

These contain groups of white blood corpuscles held in place by a thin tough covering. Lymphocytes are formed in the tonsils. Lymphocytes remove microorganisms which enter buccal cavity with food.

2. Pharynx

Pharynx is the cavity behind soft palate. It has seven openings –
1. two **nasal openings or internal nares**
2. two **openings of eustachian tubes.**
3. **gullut,** the opening of oesophagus.
4. **glottis,** the opening of larynx or trachea.
5. opening of buccal cavity into pharynx.

When food is swallowed the tracheal opening (glottis) remains closed by vulva. If a small particle of food enters the tracheal opening it is thrown out by coughing. When air is inhaled the gullet remains closed.

3. Oesophagus

Oesophagus is a muscular tube about 10 inches (25 cm) long. Food passes down the oesophagus by **peristaltic movement** of its muscular wall. Its opening into the stomach is surrounded by a ring of muscles (**Cardiac sphincter**)

4. Stomach

Stomach is an elongated sac or pouch. It lies below the diaphragm in the upper part of abdominal cavity with the liver lobes. The greater part of stomach lies towards the left.

(a) **Divisions of stomach** – stomach can be divided into three parts –
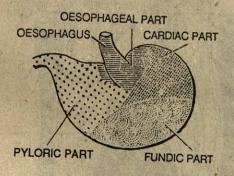
Fig. 17.12. Various parts of stomach.

(i) upper part - **cardiac stomach** or body ;
(ii) the enlarged part towards left is the **fundic stomach ;** and
(iii) the lower part nearest the intestine is the **pyloric stomach.** It opens into the duodenum.

(b) **Curves** – The upper right border of stomach is known as the **lesser curvature** and the lower left border the **greater curvature.**

(c) **Sphincter muscles** – A sphincter muscle consists of circular muscle fibres arranged around an opening, which can be closed when these muscles contract. Both the stomach openings are guarded by sphincter.

(i) The **cardiac sphincter** guards the opening of gullet into the cardiac stomach and
(ii) The **pyloric sphincter** guards the opening of pyloric stomach into duodenum.

(d) **Glands** – The mucosa of stomach contains numerous microscopic **gastric glands** that lie embedded in the gastric pits. The glands secrete **gastric juice** that contains enzymes, HCl and mucus.

(e) **Functions** – Stomach carries on the following functions –
(i) It stores food until it is partially digested.
(ii) It secretes gastric juice to aid in digestion
(iii) It churns the food into a fine pulp and mixes gastric juice.
(iv) Water and soluble foods such as sugar, alcochol and certain drugs are absorbed by stomach wall.
(v) Its acid kills bacteria that enter stomach along with food.
(vi) It produces the hormone - **gastrin** in the pyloric stomach that stimulates secretion of gastric juice.
(vii)It produces **intrinsic factor** that helps in the absorption of Vitamin B_{12}.

5. Small Intestine

Small intestine is 6 meters (20 feet) long tube of approximately 2.5 cm. (1 inch) diameter. It lies coiled up in the abdominal cavity.

Divisions of small intestine - Small intestine consists of three parts – **duodenum, jejunum** and **ileum.**

(i) **Duodenum** is the first part of intestine about 25 cm (10 inches) long and U-shaped in appearance. Its descending limb receives the opening of common bile duct and pancreatic duct.

(ii) **Jejunum** is about 2.5 meters (8 ft.) long and narrower than duodenum.

(iii) **Ileum.** The jejunum and ileum do not have a clear cut demarcation. Ileum is about 3.5 meters (12 ft.) long.

Glands – The intestinal mucosa is produced into numerous **villi** which greatly increase the area of absorption and contains numerous intestinal glands or **bruner's glands.** These secrete digestive enzymes for the digestion of proteins, carbohydrates and lipids.

Functions – Small intestine carries out following functions –

(i) Completes digestion,

(ii) Absorbs the digested food

(iii) Secrets hormones that control the secretion of pancreatic juice, bile and intestinal juice.

6. **Large Intestine** (Colon)

Large intestine is wider than small intestine. It is about 1.5-1.8 metres (5-6 ft.) long and 6 cm. (about $2\frac{1}{2}$ inch) in diameter. It lies curled outside the small intestine in the abdominal and pelvic cavities.

Divisions of large intestine - It is divided into **caecum, colon** and **rectum.**

(i) The opening of small intestine into caecum is controlled by a **ileocaecal valve** which permits the food to move down into the large intestine but not back into the small intestine. From caecum arises a worm like blind tube, the **vermiform appendix.** It is 8-10 cm (3 or 4 inches) long. In man it has no function (vestigial organ).

Sometimes the mucous living of appendix get inflamed, causing pain and discomfort. This condition is called **appendicitis.**

(ii) **Colon** is inverted U-shaped tube, divided into four parts namely **ascending colon, transverse colon, descending colon** and the **sigmoid colon.**

(iii) **Rectum** is the 15 cm (about 7 inches) long terminal tube that opens to the exterior by **anus.** Anus is guarded by two sphincter muscles.

Functions - The main functions of large intestine are

(i) absorption of water from the food.

(ii) secretion of mucous and

(iii) egestion of undigested waste matter

HISTOLOGY OF ALIMENTARY CANAL

General Plan

The wall of alimentary canal from oesophagus to rectum is made up of the following four layers –

1. Serosa or Adventitia

2. Muscular layer or **muscularis externa**
   (i) Longitudinal muscle layer
   (ii) Circular muscle layer

3. **Submucosa.**

4. **Mucousa**
   (i) Muscularis mucosa
   (ii) Lamina propria
   (iii) Mucous epithelium

These layers differ in structure and thickness in various parts of alimentary canal.

1. **Oesophagus**

(i) **Muscular coat** is thick, formed of outer longitudinal and inner circular layer; it has **striated or skeletal muscle fibres** in the upper part and smooth or **nonstriated muscle fibres** in the lower part.

(ii) **Submucosa** contains oesophageal glands.

(iii) **Mucousa** – (i) **Muscularis mucosa** is formed of outer longitudinal and inner circular layer of smooth muscles and (ii) **Mucous membrane** is stratified squamous epithelium.

2. **Stomach**

1. **Muscular coat** is thickest and formed of 3 layers **longitudinal, oblique** and **circular muscle layers.**

2. **Mucosa** - (i) Its **muscularis mucosa** is prominent and formed of outer longitudinal and inner circular muscle layers. (ii) **Lamina propria** contains gastric pits and body of gastric glands. (iii) **Mucous membrane** is formed of **columnar epithelium** is produced into **gastric glands,** also called **faveolae.**

Gastric Glands

The **gastric glands** are simple, unbranched or branched tubular glands, embedded in the

lamina propria. These are formed of the following types of cells :

(i) **Zymogen cells** or **peptic cells** or **chief cells** are pyramided cells,, present in the basal part of gastric glands. These secrete digestive enzymes of gastric juice.

(ii) **Oxyntic cells** or **parietal cells** are large oval cells bulging out of mucous membrane. These are present in the luminal part of gastric gland and secrete **hydrochloric acid** and **intrinsic factor.**

(iii) **Mucous cells** are present in the neck of gastric glands and secrete mucus.

The gastric glands are of three types –
1. **Cardiac glands** in the cardiac stomach,
2. **Pyloric glands** in pyloric stomach, and
3. **Fundic glands** in fundic stomach.

Small Intestine

1. **Muscular coat** or **Muscularis externa** is thin.
2. **Submucosa** contains blood vessels, nerve fibres and lymph spaces.
3. **Mucosa** – Intestinal mucosa is produced into numerous finger like projections, called **villi.** These increase surface of absorption.

Structure of villi – Each villus has a core of connective tissue (lamina propria) covered with a layer of columnar epithelial cells. The core contains blood capillaries, an arteriole and a venule for the absorption of amino acids and glucose. It also contains a lymphatic vessel, the lacteal for the absorption of fatty acids and glycerol. The columnar cells of surface epithelium have brush border and are absorptive in function.

The **muscularis mucosa** in thin and its circular muscle fibres extend into villi. The **lamina**
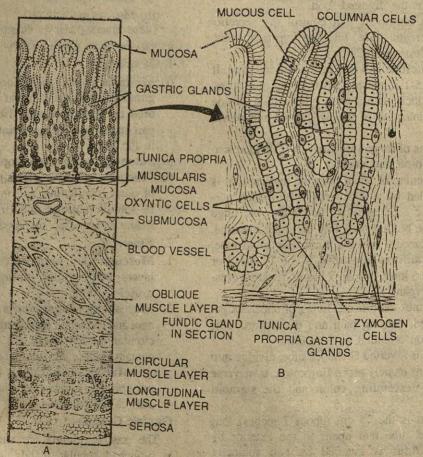
Fig. 17.13   A - T.S. Stomach   B - A part enlarged.

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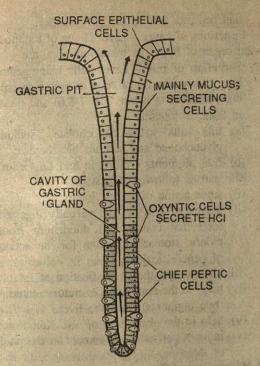
Fig. 17.14 Enlarged view of a gastric gland to show various types of cells found in gastric mucous membrane

propria is comparatively well developed and in it are embedded the **intestinal glands**, called **crypts of Lieberkuhn.** These open between the bases of villi and secrete intestinal juice.

Crypts of Lieberkuhn contain following types of gland cells –

(i) Mucus secreting - **Goblet cells**
(ii) Enzyme secreting - **Paneth cells**
(iii) Hormone secreting - **Argentaffin cells**

THE DIGESTIVE GLANDS

1. Salivary Glands

Following three pairs of salivary glands open into the buccal cavity :
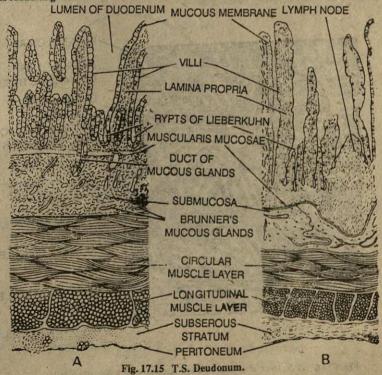
(i) **Sublingual glands** below tongue
(ii) **Submandibular glands** below lower jaw
(iii)**Parotid glands** below and in front of ears.

Mumps is an acute infection of parotid glands.

Salivary glands produce **saliva** that lubricates food and help in the partial digestion of starch (salivary amylase).

2. Liver

Liver is reddish-brown and weighs about 1.5 kg (3-4 lbs). It is formed of numerous pentagonal or hexagonal **hepatic lobules** separated by a

Fig. 17.15 T.S. Deudonum.

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sheath of connective tissue fibres, the **Glisson's capsule**. It contains numerous **interlobular blood vessels** and **interlobular bile ducts**.

(i) **Hepatic cells** – Each hepatic lobule has a **central** or **intralobular vein**, around which numerous hepatic cells are arranged in single row forming radial **hepatic cords**. The **hepatic cells** are polyhedral or rectangular. Their granular cytoplasm stores **glycogen granules** and **fat droplets**. These produce bile juice. Between the hepatic cords are present two types of channels.

(i) The **liver sinusoids** are irregular branches of interlobular vein. These lie between the hepatic cords and are filled with blood. Their wall has a few amoeboid **Kupffer cells**. These are **phagocytic** and remove toxic material from blood.

(ii) **Bile canaliculi** or **bile capillaries** form a network on the surface of hepatic cells. These join to form **bile ducts** which open into the **hepatic duct**. The hepatic ducts of various liver lobes together form the **common hepatic duct** that opens into the cystic duct

and deposits **bile** in the gall bladder.

Functions of Liver – Liver is one of the most vital organ of body. Its main functions are -

1. **Secretion of bile** – Liver cells manufacture bile. It is yellowish or reddish-brown in colour ; alkaline in nature (pH 7-8.6) and bitter in taste. It contains –
   (a) **bile - salts** - sodium taurocholate, sodium glycocholate and sodium bicarbonate
   (b) **bile pigments** - bilirubin and biliverdin.

Bile carries following functions –
   (i) stops action of gastric juice.
   (ii) makes the chyme (the partially digested food that comes into duodenum from pyloric stomach) alkaline for the action of pancreatic juice.
   (iii) bile salts in the emulsification of fat.
   (iv) helps in the removal of excretory material (bile pigments) from the liver.
   (v) help in the absorption of Vit. K.
   (vi) induces peristaltic movement in the wall of intestine.

2. **Metabolism of Glucose**
   (i) Glycogenesis - Excess of glucose from

HEPATIC LOBULE
INTERLOBULAR CONNECTIVE TISSUE
CENTRAL VENULE OF LOBULE
CAPILLARY SINUSOIDS LINED BY KUPFFER CELLS
BILE CAPILLARIES
RADIAL CHAINS OF HEPATIC CELLS
INTRALOBULAR VENULE
GLISSON'S CAPSULE
PORTAL TRIAD
CONNECTIVE TISSUE SHEATH
LYMPHATIC VESSEL
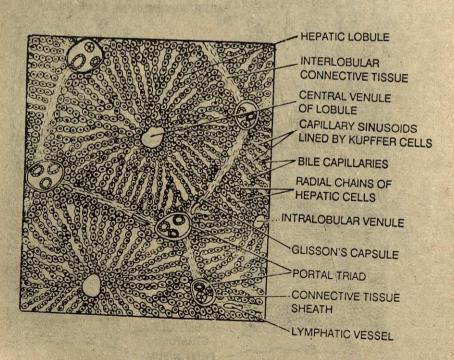
Fig. 17.16 T.S. liver showing detailed structure of a hepatic lobule

blood is converted into **glycogen** and stored in the liver cells.

(ii) **Glycogenolysis** - Whenever needed by the body, the glycogen stored in liver cells is converted into glucose.

(iii) **Gluconeogenesis** - To overcome shortage of sugar, glucose is synthesized from amino acids or fatty acids and glycerol.

3. **Synthesis and storage of fat**

(i) **Lipogenesis** - Excess of glucose is converted into fats to be stored in adipose tissue.

(ii) **β-oxidation** - Denaturation of fatty acids and phosphorylation of fats takes place in liver cells.

4. **Deamination of proteins** - Excess of amino acids undergo deamination producing **pyruvic acid** and **ammonia**.

5. **Synthesis of urea**. Ammonia produced by deamination of amino acid in hepatic cells are converted to **urea** (**Kreb's Hanslete cycle** or **Kreb's ornithine - arginine cycle**).

6. Synthesis of vitamin A - from carotin and storage of Vit. A, B$_{12}$ and D.

7. **Synthesis of albumin** from amino acids.

8. **Storage of inorganic substances** like iron, copper.

9. **Formation of blood proteins** (like **prothrombin, fibrinogen**) are synthesized in liver cells. These are necessary for blood clotting

10. **Phagocytosis** - Kupffer cells destroy dead R.B.Cs. The bile pigments **bilirubin** and **biliverdin** are formed from the breakdown of haemoglobin.

11. Produce **heparin**, an enzyme which prevents clotting of blood inside the blood vessels.

12. Formation of R.B.Cs. during foetal life.

13. Manufactures lymph

14. **Detoxication** - Liver cells either inactivate the toxic substances like cresol, carbolic acid etc. (produced by intestinal bacteria) or convert them to nontoxic substances. Similarly prussic acid produced during metabolism is converted into nontoxic substance.

15. Liver is centre of heat production.

3. Pancreas

Pancreas is a diffused leaf-shaped gland. It is a compound gland, formed of **exocrine part.** and
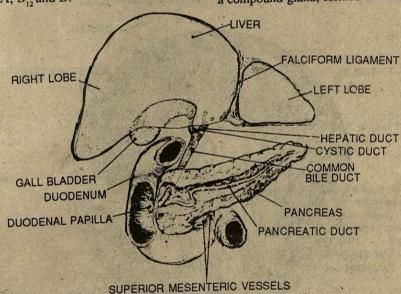
Fig. 17.17 Diagram to show position of gall bladder and pancreas.

endocrine part.

1. The **exocrine part** is formed of lobules or **acini** held together in the connective tissue. Each **acinus** is formed of single layer of large glandular **acinous cells** that manufacture **pancreatic juice**. Pancreatic juice contains following enzymes –
   (i) **Trypsinogen** (inactive trypsin)
   (ii) **Chymotrypsinogen** (inactive chymotrypsin)
   (iii) **Steapsin** (Active)
2. **Endocrine part** is represented by patches of cells in the exocrine part and are called **islets of Langerhans**, these are formed of two types of cells
   (i) **α-cells.** These produce hormone **glucagon.** It induces conversion of stored glycogen into glucose in liver cells ; causes release of glucose in blood and elevation of blood sugar level.
   (ii) **ß-cells.** These produce hormone **insulin.** It promotes formation of glycogen from glucose for storage in liver and muscle cells and reduces blood glucose level. The deficiency of insulin causes **diabetes.**

The two hormones insulin and glucagon are **antagonistic** in function.

Necessity of Digestion

Digestion is necessary because the organic constituents of food like, carbohydrates, proteins and lipid are formed of complex **macromolecules.** These are too big to diffuse through gut wall and enter the blood stream or for cells to utilize them for energy. During digestion **carbohydrates** are hydrolysed into **glucose** ; **proteins** into amino acids and **fat molecules** into fatty acids and glycerol molecules.

Kinds of Digestion

During digestion both physical and chemical composition of ingested food changes. Therefore, digestion is both **mechanical** and **chemical.**

Mechanical digestion includes (i) physical breaking of solid pieces into minute dissolved particles and preparing food for chemical digestion; (ii) churning of food for proper mixing of enzymes;(iii) Movement of food along the digestive tract.

Chemical digestion includes hydrolysis of food macromolecules with the aid of enzymes present in the digestive juices.
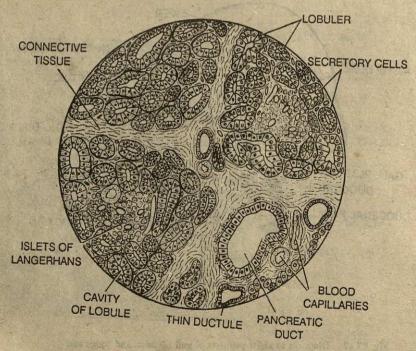
Fig. 17.18 T.S. Pancreas.

PROCESS OF DIGESTION

1. Digestion of Food in Buccal Cavity

The food is chewed by the grinders (premolars and molars). The tongue pushes the food towards the grinders and helps in mixing the saliva. It is lightly acidic (pH-6-7) and contains mucus, the digestive enzyme **ptyalin** or **salivary amylase**.

Ptyalin is absent in the saliva of many animals including domestic herbivores and predatory carnivores. But it is present in man and pigs. Chewing of food helps in ptyalin action. About 30% starch is digested by ptyalin in buccal cavity.

Functions of Saliva

(i)   The digestive enzyme **ptyalin** or **salivary amylase at pH-7** hydrolyses starch and glycogen into **maltose** and **isomaltose** and small dextrins.

$$(C_6H_{10}O_5)_n + H_2O \xrightarrow{\text{Ptyalin}} C_{12}H_{22}O_{11}$$

(ii) Some amount of maltose sugar is hydrolysed into glucose by the enzyme **maltase**.

(iii) **Mucus** present in saliva mixes with food and makes it soft and viscous to be easily masticated by the grinders.

(iv) With saliva the churned food forms a **bolus** to be swallowed easily.

(v)   When there is no food in the buccal cavity saliva keeps tongue and buccal cavity moist, and helps in speaking.

(vi) The enzyme **polysaccharidase** dissolves cell wall of bacteria and destroys them.

(vii) Bicarbonates, phosphates and mucin act as buffers.

(viii) Saliva helps in tasting the food.

2. Deglutition (Swallowing)

The process of swallowing includes three steps—

(1) **Movement of food from buccal cavity to pharynx** – By the voluntary action of tongue muscles, the masticated food moistened with saliva is formed into a **bolus** and is propelled into phrynx.

(2) **Movement of food from pharynx to oesophagus** – The involuntary contraction of pharyngeal muscles pushes the food into oesophagus. During this time the buccal cavity and openings of nasopharynx and larynx remain closed.

Table 17.1 : Summary of Physical Digestion

ORGAN	MECHANICAL PROCESS	RESULT
1. Buccal cavity (Teeth & Tongue)	1. Mastication	Chewing of food; reduced size of food particles and mix them with saliva.
	2. Deglutition	Swallowing of food
2. Pharynx	Deglutition	''
3. Oesophagus	1. Deglutition	''
	2. Peristalsis	Worm-like movements in the wall of oesophagus pushing the food downwards into the stomach.
4. Stomach	1. Churning	By the contraction and relaxation of circular muscles in the wall of stomach the food is churned into a paste and is mixed well with the gastric juice. Food paste is called chyme.
	2. Peristalsis	Moves food towards pyloric aperture.
5. Small Intestine	1. Mixing contractions	Forward and backward movement of food in intestine for mixing digestive enzymes.
6. Large Intestine (i) Colon	1. Mixing contractions	Churning movements
	2. Peristalsis	Movement of food towards rectum
(ii) Rectum	Defaecation	Bowel movement or emptying of undigested left over.

(i) Buccal cavity is closed by the elevation of tongue.

(ii) The soft palate is elevated and tensed to close the nasopharynx.

(iii) Epiglottis blocks the glottis (the laryngeal opening).

(3) **Movement of food from Oesophagus to stomach** – Due o peristaltic movements in the oesophageal wall, the bolus travels down through oesophagus into stomach.

CHEMICAL DIGESTION

Digestion of Carbohydrates

1. In Buccal Cavity

Digestion of Carbohydrates (starch) begins in the buccal cavity. The enzyme **salivary amylase** or **ptyalin** hydrolyses starch into maltose, isomaltose and small dextrins in almost neutral or slightly alkaline medium. About 30 per cent of food starch is hydrolysed in mouth. If you chew few raw rice or a piece of bread slowly, it will taste sweeter because of hydrolysis of starch into maltose (sugar). Chewing helps in ptyalin action.

Salivary amylase is absent in the saliva of many mammals such as cows, buffaloes, tigers and lions. But pigs secrete ptyalin because they feed on roots and tubers containing stored starch.

2. In Stomach

Gastric juice does not contain any carbohydrate hydrolysing enzyme. HCl destroys ptyalin present in food.

3. In Duodenum

The digestive enzyme **pancreatic amylase** or **amylopsin** present in the pancreatic juice hydrolyses remainder starch into maltose, isomaltose and small dextrins.

4. In Small Intestine

Intestinal juice – **saccus entericus** contains following **carbohydrases** :

isomaltase, maltase, lactase and sucrase

1. Maltose $\xrightarrow{\text{Maltase}}$ Glucose

2. Isomaltose $\xrightarrow{\text{Isomaltase}}$ Glucose dextrine

3. Lactose $\xrightarrow{\text{Lactase}}$ Glucose + Galactose

4. Sucrose $\xrightarrow{\text{Sucrase}}$ Glucose + Fructose

All these enzymes work in alkaline medium at *pH*-8.

Digestion of Lactose and Flatulence

Lactose digesting enzyme **lactase** is absent in most of the adult mammals, except human beings. But some human adults can not digest it because in them production of lactase gradually dwindles with age. The undigested lactose in food gets fermented in the intestine producing gases and acids. This results in flatulence, intestinal cramps and diarrhoea.

But an intake of yoghurt or curd poses no digestive problem because in curd lactose is fermented into lactic acid left in the whey of curd.

Digestion of Cellulose

Cellulose-hydrolyzing enzyme is called **cellulase**. It is found in only in few bacteria, protozoans and some invertebrates (like silverfish, earthworm and shipworm). Vertebrates are unable to produce cellulase. In herbivorous vertebrates, cellulose digesting micro-organisms live as symbionts in various parts of alimentary canal.
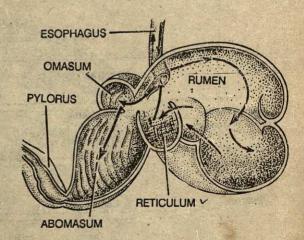
Fig. 17.19 Structure of stomach of ruminant mammals.

1. In **ruminant mammals** like cows, buffaloes sheeps and goats, the stomach is highly specialized with four chambers - **rumen, reticulum, omasum and abomasum**.

The **rumen** and **reticulum** are packed with anaerobic micro organisms. These microbes

ferment cellulose into short chain fatty acids such as acetic acid and propionic acid. These are absorbed by the stomach wall.

Cellulose digestion is made more efficient by **rumination**. The boluses of food are drawn from rumen into the buccal cavity to be regurgitated and rechewed to break the plant fibres more finally so as to make them more accessible to the microorganisms. Fermented cud along with masses of micro-organisms are moved to smaller **omasum** for water absorption. The bolus then moves into **abomasum** where microorganisms are also digested along with plant materials. Thus the **microbial fauna of ruminant stomach helps in the digestion of cellulose and serves as a source of protein.**

2. In rats, guinea pigs and rabbits, cellulose digesting microorganisms harbour caecum and appendix. These do not ruminate but eat their faeces containing much undigested cellulose. This is called **corpophagy.** This helps in fermentation and absorption of undigested cellulose again.

Glycogen present in the food of carnivores can not be utilized because as soon as the animal is killed, its muscle and liver glycogen is rapidly degraded into lactic acid by the enzymes.

Digestion of Proteins

Digestion of proteins occurs in stomach and intestine. The protein hydrolysing enzymes are called **proteases** and **peptidases.** All these enzymes are secreted in inactive form and are called **proenzymes**, because if secreted in active form, these would hydrolyse cellular and extracellular proteins of the organism itself. Proenzymes (propepsin, prorennin etc.) are activated either by optimal pH or some specific protease only at the sites of their action.

Hydrolysis of proteins does not occur in mouth. Saliva denatures raw proteins if taken uncooked.

Digestion of Proteins in Stomach

Gastric juice contains enzymes **pepsin** and **rennin.**

1. **Pepsin** is secreted in inactive form **pepsinogen.** In acidic medium it is converted into active pepsin and an inactive peptide. Pepsin is—

an **endopeptidase.** It works at pH - 2 (acidic) and hydrolyses proteins into proteoses and peptones.

$$\text{Proteins} \xrightarrow{\text{pepsin}} \text{Proteoses} + \text{Peptones}$$

Pepsin also helps in **coagulation of milk.** It hydrolyses soluble casein into **paracasein** and whey protein. Paracasein is precipitated as **calcium paracaseinate** to form solid curd. This is called **coagulation of milk.**

Pepsin can hydrolyse a variety of proteins even collagen protein of connective tissue fibre. However, it can not hydrolyse keratins of hair, skin, nail or horn.

2. **Rennin** is secreted as inactive **pro-rennin.** At acidic pH rennin hydrolyses casein into paracasein causing milk coagulation. It is not secreted in all mammals. It is absent in adult cows, human beings and even in infants. In human being this coagulation is carried out by pepsin and other milk coagulating enzymes.

Digestion of Proteins in Duodenum

Pancreatic proteases are **trypsin, chymotrypsin** and **carboxipeptidases.** But these are secreted as inactive zymogens or proenzymes–called **trypsinogen** and **chymotrypsinogen**. Initially intestinal protease - enterokinase or **enteropeptidase** hydrolyses inactive **trypsinogen** into active **trypsin** and an inactive peptide. Trypsin then hydrolyses the remaining typsinogen into trypsin and also activates chymotrypsinogen into chymotrypsin.

$$\text{Trypsinogen} \xrightarrow{\text{Enterokinase}} \text{Trypsin}$$

$$\text{Chymotrypsinogen} \xrightarrow{\text{Trypsin}} \text{Chymotrypsin}$$

$$\text{Trypsin} + \text{Protein} \longrightarrow \text{Peptones} + \text{Polypeptides}$$

$$\text{Chymotrypsin} + \text{Protein} \longrightarrow \text{Peptones} + \text{Polypeptides}$$

1. **Trypsin** - It acts in alkaline medium (pH-8) and hydrolyses basic proteins into peptides. It can not hydrolyse keratins and casein and so it cannot coagulate milk, but can hydrolyse blood protein fibrinogen into fibrin.

2. Chymotrypsin - It also functions at pH-8. It hydrolyses proteins into peptides and also co-agulates milk.

3. Carboxypeptidases - These are **exopepti-dases**. These hydrolyse terminal peptide bonds in a polypeptide chain and from it remove the last amino-acid.

Digestion of protein in Intestine

The intestinal juice is also alkaline. It contains following protein hydrolysing enzymes.

1. Enteropeptidase (or enterokinase) activates trypsinogen of pancreatic juice.

2. Dipeptidases and Tripepidases hydrolyse polypeptide chains into dipeptides and tripeptides respectively.

3. Aminopeptidases hydrolyze terminal peptide bond of the peptide chain and remove last amino acid from the chain.

Most vertebrates are unable to digest certain fibrous animal proteins like **kera-tins** of hair, skin, nails and hooks, **silk fi-broin** and wool protein. In carnivorous animals these fibres accumulate in the intestine causing its occlusion. Some insects can digest such fibrous protein and destroy silk fabrics and woollen garments.

Endopeptidases and Exopeptidases

Digestion of Fat

Fat hydrolysing enzymes are called **lipases**. Being water soluble, these can work only on water adjoining surfaces of fat droplets. Therefore the efficiency of lipases depends on the availablity of surface area of fat droplets. The smaller the size of droplets, the larger is the surface area in relation to its mass. Therefore, lipases can hydro-lyse fats only when their large molecules are broken into tiny droplets forming emulsion. It means **emulsification of fats prior to digestion is an essential step.**

1. Fats remain unchanged in buccal cavity because saliva lacks both fat emulsifying agent and also the lipase.

2. A mild hydrolysis of fats into **fatty acids** and **glycerol** occurs in stomach by the activity of **gastric lipase.**

Fig. 17.22 Why are there two endopeptiolases in intestine when there is already one in stomach? The endopeptidases trypsin and chymotrypsin of pancreatic juice hydrolyze different types of linkages in a polypeptide.

Early Experiments on Digestion

1. SPALLANZANI (1780) obtained gastric juice from live owl by putting sponges down the throat and then squeezing it out, and showed that gastric juice can digest proteins but not carbohydrates.

2. Army surgeon WILLIAM BEAUMONT studied 'open stomach' of a canadian trapper–Martin who had developed a permanent opening in his stomach wall by a gun shot. He established the chemical nature of digestion in human stomach.

3. Eminent Russian physiologist PAVLOV made a pouch of gastric mucosa from a dog's stomach. He connected it to the main stomach by a muscle band having nerve fibres and blood vessels. The pouch was opened to the exterior but was not connected with the lumen of stomach. This **Pavlov pouch** was used in study-ing effects of feeding on gastric secre-tion.

Table 17.2 : Summary of Chemical Digestion in Mammals

Digestive Juice and Enzyme	Source	Site of Action	Food Digestion	Resulting Products
1. Saliva	Salivary Glands	Buccal cavity		
Salivary amylase			Starch, destrin and glycogen (polysaccharides)	Maltose, isomaltose (Disaccharides)
2. Gastric Juice	Gastric glands	Stomach		
1. HCl	''	''	Makes medium	acidic
2. Pepsin	''	''	Proteins	Proteoses and peptones (partial digestion of protein)
			Casein (milk)	Paracasein (curd)
3. Rennin	''	''	Casein (milk)	Paracasein (curd)
4. Gastric lipase	''	''	Emulsifies fats (butter, cream etc.)	Fatty acids and glycerol.
3. Bile (No enzymes)	Liver	Duodenum	Emulsifies fats i.e. Large fat droplets	Small fat droplets
4. Pancreatic juice	Pancreas	Duodenum		
1. Trypsin	''	''	Proteins	Proteoses and peptides
2. Chymotrypsin	''	''	Proteins (casein)	Peptones (paracasein)
3. Pancreatic amylase (amylopsin)	''	''	Starch	Maltose
4. Lipase	''	''	Bile emulsified fats (triglycerides)	Fattty acids and glycerol (Monoglycerides)
5. Carboxypeptidases	''	''	Peptides	Separates terminal amino acids.
6. Nuclease	''	''	Nucleic acids	Nucleotides
5. Intestinal juice (Saccus entericus)	Intestinal glands	Small Intestine		
1. Amino peptidase	''	''	Peptides	small peptides + Amino acids
2. Dipeptidase	''	''	Dipeptides	Aminoacids
3. Tripeptidase	''	''	Tripeptides	Amino acids
4. Enterokinase (enteropeptidase)	''	''	Trypsinogen (inactive)	Trypsin (active)
5. Nuclease	''	''	Nucleic acids	Nucleotides
6. Nucleotidase	''	''	Nucleotides	Nucleosides
7. Nucleoside phosphorylase	''	''	Nucleotides + phosphate	Nitrogenous bases + pentose phosphate
8. Maltase	''	''	Maltose	Glucose
9. Sucrase	''	''	Sucrose	Fructose and glucose
10. Lactase	''	''	Lactose	Glucose and galactose

(iii) Fat Digestion in Duodenum

Bile salts brought into the duodenum in bile emulsify fats breaking them down into small droplets.

Pancreatic lipase present in the pancreatic juice hydrolyses triglyceride fats into diglycerides and monoglycerides.

(IV) Digestion of Fats in Intestine

Intestinal lipase hydrolyses diglycerides and triglycerides into acids and **monoglycerides**.

CONTROL OF RELEASE OF DIGESTIVE JUICES

The digestive juices are secreted only when these are required and in proper amount. Their release is stimulated by three stimuli - (i) **nervous** (ii) **mechanical** and (iii) **chemical** (hormonal).

1. **Secretion of Saliva**

    Secretion of saliva is controlled by **reflex mechanism**. Chemical, mechanical, olfactory or visual stimuli are carried to the **salivatory nuclei** present in the posterior part of medulla. These send effect impulses in the salivary glands, stimulating them to release saliva.

2. **Secretion of Gastric juice**

    The stimulation of gastric juice secretion from the gastric glands occurs in three phases and is controlled by **nervous and chemical excitations**.

    1. **Cephalic phase** - of gastric secretion is under nervous control and is influenced both by unconditioned and conditioned reflexes. The taste of food (unconditioned reflex), the sight, smell or even thought of food (conditioned reflex) stimulate gastric secretion even before the food enters the stomach. It is called **appetite juice**.

    2. **Gastric phase** - When food enters stomach, the products of protein digestion stimulate mucosa of pyloric stomach to release a hormone, **gastrin** into the blood in stomach capillaries. On reaching the gastric glands, gastrin accelerates secretion of gastric juice. Distention of stomach due to presence of food also causes release of gastrin.

    3. **Intestinal phase** - When chyme from stomach enters the duodenum, its fat component stimulates instestinal mucosa to secrete **enterogastrone** hormone. It enters the blood stream and on reaching stomach, inhibits the secretory activity of gastric glands and also influences the gastric motility.

3. **Secretion of Pancreatic Juice**

    The secretion of pancreatic juice is both under nervous and hormonal control.

    (1) **Nervous control** - It includes the reflexes caused by seeing or tasting food. The secretory cells of pancreas are excited by the release of acetylecholine at the nerve endings of vagal nerve fibres.

    (2) **Hormonal control** - When acidic chyme from stomach enters duodenum, its acid and fats stimulate duodenal mucosa to liberate hormone **secretin** and **pancreozymin**. Through hepatic portal system these reach pancreas and stimulate its secretion.

    (i) **Secretion** - Stimulates the cells of intralobuler to secrete watery portion of pancreatic juice and the bicarbonates. This alkaline fluid neutralizes the acid chyme entering the duodenum.

    (ii) **Cholecystokinin-pancreozymin (CCK - PZ)** - It induces acinous cells of pancreas to secrete pancreatic juice. It also stimulates contraction of gall bladder and relexation of shpincter of Oddi so that bile juice can pass into the duodenum.

    Cholecystokinin-pancreozymin was originally thought to be two separate hormones-pancreozymin for pancreas and cholecystokinin for gall bladder. But now it has been identified as a single substance with dual role.

4. **Secretion of Bile Juice**

    Bile secretion is exclusively under chemical control.

    (a) **Bile salts** - The bile salts like **sodium glycocholate** and **sodium taurocholate** are absorbed from the intestine and are carried to liver through hepatic portal circulation and are again excreted there.

    (b) **Hormone** - When food enters duodenum it stimulates its mucosa to secrete **cholecystokinin-pancreozymin**. It brings about contraction of gall bladder and relaxation of sphincter of Oddi (which is present in the common bile duct). In addition, vagus stimulation causes the same effect and brings expulsion of the bile into the duodenum.

5. **Secretion of Intestinal Juice (Saccus Entericus)**

5. The secretion of digestice juice from the intestinal mucosa is more or less continuous but it is considerably increased during the process of digestion. The stimulation is brought about both by mechanical as well as chemical stimuli.

    (a) **Mechanical stimuli** - These are produced by the presence of food in the intestine. The food material induces the local sense organs (**Meissner's plexus**). These mechanical irriations stimulate the secretion of intestinalstimulate the secretion of intestinal juice.

    (b) **Hormonal stimuli** - The hormone **enterocrinin** secreted by intestinal mucosa induces increased production of digestive enzymes. Secretin also plays some role in stimulation of intestinal mucosa.

Table 17.3: Hormone of the digestive tract

	Hormone	Source	Stimulus	Action
1.	Gastrin	Gastric mucosa	Partially digested	Stimulates secretion of gastric juice
2.	Enterogastron	Intestinal mucosa of small intestine	Fats	Inhibits gastric secretion and mobility
3.	Secretin	Intestinal mucosa of small intestine	Partially digested proteins, fats and acid	Stimulates secretion of pancreatic juice
4.	Cholecystokinin Pancreozymin	Intestinal mucosa	Fats, partially digested Proteins and acids and also presence of food in dudenum.	Stimulates (release of bile from Stimulates and secretion of pancreatic juice).

ABSORPTION OF DIGESTED FOOD

1. Absorption in Buccal Cavity and Oesophagus

No appreciable absorption of food material takes place.

2. Absorption in stomach

Water, alcohol, inorganic salts and some amount of glucose are absorbed by the stomach wall.

3. Absorption in Intestine

Most of the digested nutrients are absorbed in the small intestine. The villi on the inner surface of intestine and the microvalli on the free surface of mucosal epithelial cells enhances absorption capacity of intestine. The various processes involved in the absorption of nutrients across the plasma membrane of intestinal cells are classified into two categories.

    1. Passive absorption   by diffusion and by osmosis

    2. Active absorption

Passive absorption

The end products of carbohydrate digestion (glucose, galactose, levulose, xylose, mannose etc.) and of protein digestion (amino acids) are absorbed by intestinal epithelium by simple diffusion. Simple diffusion occur only when -

(i) Nutrient molecules are small and water soluble.

(ii) Corcentration of nutrients is higher in the intestinal lumen than inside the cell.

Substances like fructose and mannose are absorbed by **facilitated diffusion**. It is modified passive transport where cell does not energy but a carrier molecule is required. The carrier molecule of plasma membrane combines with the molecule of transportant and its transportation become more rapid than simple diffusion.

2. Active Absorption

Substances of high nutritional value e.g. Na⁺, glucose, galactose and amino acids are absorbed

actively and completely from the intestine. By active absorption cells can absorb even when the concentration of a substance is much lower in the intestinal lumen than in the intestinal cells and blood.

Energy is spent by the cells while obtaining substance by active transport. Active absorption occurs more rapidly than diffusion. If cells are poisoned with cyanide or depressed by cold, active absorption caeses :

The mechanism of absorption of a substance against concentration gradient is analogous to a pump carrying water against gravity. Specific membrane protein acts as a carrier. The energy required for this process is derived from ATP. Sodium pump of membrane helps in the active absorption of Na⁺.

Absorption of Fat

The end products of fat digestion are mono., di- and triglycerides and fatty acids. These are insoluble in water and can not be absorbed directly. With the help of bile salts in intestine these are first incorporated into small, spherical, water - soluble droplets, called **micelles**. Each micelle is an aggregate of many molecules, consisting of fatty acids, glycerides, sterols and fat soluble vitamins.

Absorbed fatty acids and glycerides enter the lacteals where in the lymph these form fat droplets, called **chylomicrons**.

NUTRITIONAL REQUIREMENTS

There are five categories of nutrients required by our body and should be present in the food we eat. These are (i) Carbohydrates, (ii) Fats, (iii) Proteins, (iv) Minerals and (v) Vitamins.

1. Carbohydrates

The carbohydrates are composed of carbon, hydrogen and oxygen. These are the main sources of energy. The oxidation of carbohydrates during respiration yields energy which is stored in ATP and utilized whenever needed. One gram of carbohydrates yield about 4.1 Kcal. of energy when oxidised, in the body tissues. This is called **calorific value** of carbohydrates,

Sources of Carbohydrate – The carbohydrates we take are in the form of sugar and starches. Except lactose (milk, sugar) all other sugars are derived from the plants. Their major sources are gur, sugar, honey, fig, grapes, sugar cane, resins, sweet and fruits etc.

Starches – These are mainly stored in stem roots and seeds of green plants. These are found in cereals - wheat, maize, barley, rice and sago; potato (stem), sweet potato and beet (roots). **Glycogen** is the animal starch present in muscles and liver.

Metabolism of Carbohydrates – After digestion carbohydrates are hydrolysed into smallest unit of sugars - **glucose**. It is absorbed and carried to the liver, from where it is distributed to different parts of the body. The excess of glucose is converted into **glycogen** and is stored in the hepatic cells and muscles.

Effect of Shortage and Excess of Carbohydrates – Average 55-75 per cent of total food calories are obtained from carbohydrates. Atheletes, labourers need high carbohydrate diet. The shortage or **deficiency of carbohydrates** in daily food leads to reduction in weight and loss of working efficiency. In absence of carbohydrates proteins are used for liberating energy. This affects liver and nervous system. The **excess of carbohydrates** in food causes obesity which may lead to blood pressure.

Functions of Carbohydrates

1. Carbohydrates are major source of energy. These are supplied to **different** body cells as glucose or blood sugar. During respiration, in the presence of oxygen, these are oxidised to CO_2 and H_2O releasing energy. Carbohydrates are most suitable for energy because these have relatively more oxygen and consequently require less oxygen during oxidation.

2. These are stored as glycogen in animals and as starch in plants.

2. Fats

These are also composed of carbon, hydrogen and oxygen. These are formed of fatty acids and glycerol. Fats which are in liquid state at room temperature (20°C) are called **oils**.

One gramme of fat gives twice the energy given by one gramme carbohydrate. Its calorific value one gramme of fat gives rise to 9.45 kcal of energy. Its physiological value (*i.e.* enery released by 1 gm of fat in body tissues) is 9 kcal.

Sources of Fats - Examples of animals fats are dairy products such as milk, butter, cheese, egg, yolk, meat, fish. Examples of vegetable fats and oils are mustard seeds, ground nut, coconut, linseed and dry-fruits. etc.

Functions of Fats

1. Fats are very rich source of stored energy for the body. 2. In body, fats are stored in adipose tissue. The adipose tissue protects the internal organs of the body from shocks and jerks. 3. Fats are also important component of the cytoplasm and cell membranes. 4. Fats help in the absorption of fat soluble vitamins A, D, E and H.

Table 17.4 : Important Food Items and Their Fat Percentage

	Food	Percentage fat
1.	Butter	81%
2.	Oil seeds and nuts	37 to 64.5%
3.	Meat	13.3%
4.	Eggs	13.3%
5.	Milk (Cow)	4.1%
6.	Cheese	32.9%

Metabolism of Fat - As a result of digestion, fats break into glycerol and fatty acids. These are carried by the blood into the liver and from here to adipose tissue under the skin for storage. Fat is metabolised in the liver.

Effect of deficiency and excess of fats - In man 10 - 25 per cent of total caloric requirement is obtained from fats. Atheletes, weight-lifters and labourer need more than 40 per cent of their food calories from fats.

The shortage of fat in daily food causes dry and rough skin. Body becomes lean and thin and weak. The excess of fat in daily food causes obesity which may lead to high blood pressure and heart diseases.

Essential Fatty Acids

Linoleic, linolenic and arachidonic acids are polyunsaturated fatty acids. These can not be synthesized by the animals, but are essentially required as structural components of plasma membrane. These are called **essential fatty acids.**

The excess of intake of saturated fats like butter, ghee and hydrogenated vegetable oils enhances blood cholesterol level. Persons with sedentary habit are advised to avoid saturated fats and cholesterol.

3. Proteins

Proteins contain carbon, hydrogen, oxygen, and nitrogen. Sulphur is also present in some proteins. Proteins are formed of amino acid units. The quality of proteins depends upon the amino acids they contain. There are about 20 amino acids which are essential for human growth and development. Human body cannot synthesise these amino acids. Therefore, these amino acids must be present in the proteins we eat. For the same reason, these amino acids. Lack of these amino acids in diet, specially in children, causes retarded physical and mental growth. Animal proteins are called first class proteins because they contain all the essential amino acids. Milk protein **casein** and egg protein **albumin** are examples of animal proteins.

Sources of Vegetable Proteins - Rich sources of vegetable proteins are pulses, legumes, nuts, fresh fruits and dry fruits. Kaju and soyabeans are considered to be the best source of first class vegetable proteins.

Functions of Proteins - 1. Proteins are essential components of cytoplasm and, therefore, very essential for growth. 2. Proteins are essential for the repair of worn out tissue. 3. In case of deficiency of carbohydrates and fats, proteins are utilised for energy. 4. The muscles of body are formed from proteins. 5. Proteins act as enzymes and hormones and control various body activities.

Metabolism of Proteins - As a result of digestion proteins are hydrolysed into amino acids. These are absorbed by blood and transported to various parts of the body. Inside the cells, the amino acids are used in a number of constructive activities leading to the synthesis of proteins, new cytoplasm and the nucleoproteins.

Diseases caused by deficiency of proteins – 1. The deficiency of proteins causes diarrhoea-like symptoms because the digestive enzymes are not synthesised in required amount due to shortage of required amino acids. 2. The central nervous

Table 17.5 : Important Food items and their Protein

Food Items	Protein in gm. Pr 100 gm	Food Items	Protein in gm Pr 900 gms
Cereals	6.0 to 13.0	Fish	15.0 to 26.0
Pulses	21.0	Eggs	13.0
Vegetables (leafy)	1.0 to 7.0	Milk	3.2 to 4.3
Fruits (Fresh)	1.2	Goat meat	21.4
Fruits (dry)	2.35	Pork	18.7
Soyabeans	43.2	Beef	22.6
Groundnut	26.7	Liver	19.3
Coconut (dry)	6.8		

system may also get affected by shortage of proteins. 3. Liver fails to function normally. 4. The deficiency of proteins in children causes **Kwashiokor** and **Marasmus diseases.**

Essential Amino Acids

Methionine, threonice, tryptophan, valine, leucine, isoleucine, lysine and phenylalanine etc. are **essential amino acids** for human nutrition. **Semi-indispensible amino acids** are arginine, and histidine. The remaining glycine, alamina, serine, cysteine, proline aspartic acid, tyrosine and glutamis acid are non-essential amino acids.

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4. Minerals

Minerals form the chief building materials of bones and teeth. About 4 percent of human body weight is made up of minerals. Minerals also play important role in body mecalcium, phosphorus, iron and iodine. For example, bones and teeth are largely formed of calcium phosphate. Iron is present in haemoglobin of red blood corpuscles.

Sources of Minerals - Minerals are available from milk, fruits, vegetables, meat and water etc.

5. Vitamins

Vitamins are essential for proper utilization of carbohydrates, fats, proteins and minerals by the body. They are needed in minute quantities but are very essential for our health and vitality. They protect us from diseases. Vitamins are classified into two groups on the basis of their solubility in

Table 17.6 : Mineral Elements : Their Source and Functions

ELEMENT	SOURCE IN HUMAN DIET	MAJOR FUNCTIONS
MACRONUTRIENTS		
Calcium (Ca)	Dairy foods, eggs, green leafy vegetables, whole grains, legumes, nuts	In bones and teeth; blood clotting; nerve and muscle action; enzyme activation
Chlorine (Cl)	Table salt (NaCl)	Water balance; digestion (as HCl); principal negative ion in fluid around cells
Magnesium (Mg)	Green vegetables, meat, whole grains, nuts, milk, legumes	Required by many enzymes; found in bones and teeth
Phosphorus (P)	Dairy foods, eggs, meat, whole grains, legumes, nuts	In nucleic acids, ATP, and phospholipids; bone formation; buffers; metabolism of sugars
Potassium (K)	Meat, whole grains, fruits, vegetables, legumes	Nerve and muscle action; protein synthesis' principal positive ion in cell.
Sodium (Na)	Table salt, dairy foods, meat, eggs, vegetables	Nerve and muscle action; water balance; principal positive ion in fluid around cells

ELEMENT	SOURCE IN HUMAN DIET	MAJOR FUNCTIONS
Sulphur (S)	Meat, eggs, dairy foods, nuts, legumes	In proteins and coenzymes; detoxification of harmful substances
MICRONUTRIENTS		
Chromium (Cr)	Meat, dairy foods, whole grains, dried beans, peanuts, brewers' yeast	Involved in glucose metabolism
Cobalt (Co)	Meat, tap water	Vitamin B_{12}; formation of erythrocytes
Copper (Cu)	Liver, meat, fish, shellfish, legumes, whole grains, nuts	In active site of many redox enzymes and electron carriers; production of hemoglobin; bone formation
Fluorine (F)	Most water supplies	Improves resistance to tooth decay
Iodine (I)	Fish, shellfish, iodized salt	In thyroid hormone
Iron (Fe)	Liver, meat, green vegetables, eggs, whole grains, legumes, nuts	In active site of many redox enzymes and electron carriers; hemoglobin; myoglobin
Molybdenum	Organ meats, dairy foods, whole grains, green vegetables, legumes	Required by some enzymes
Selenium (Se)	Meat, seafood, whole grains, eggs, chicken, milk garlic	Involved in metabolism of fats
Zinc (Zn)	Liver, fish, shellfish, and many other foods	Required by some enzymes; involved in physiology of insulin

fats and water : (1) Fat soluble vitamins are vitamins, A, D, E and K. (2) Water soluble vitamins are vitamins C and B-complex. Vitamin D is the only vitamin which our body skin can synthesise in sunlight. Vitamin B-*complex* actually consists of several vitamins like vitamin B_1, B_{12}, B_6 etc.

Besides the five nutrients, water is also a necessary food element. Water forms nearly two-thirds of our body weight. It is important for transportation of nutrients and metabolic processes.

Table 17.7 : Vitamins and their Characteristics

Name, formula and principal effect	Important sources	Physiological functions	Result of deficiency or absence (in man except as noted)
Vitamin A A – $(C_{20}H_{30}O)$, anti-xerophthalmic (fat-soluble)	Plant form (carotene, $(C_{40}H_{56})$ in green leaves carrots, etc.; is changed in liver to animal form $(C_{20}H_{30}O)$, present in fish-liver oil (shark) ; both forms in egg yolk and milk.	Maintains integrity of epithelial tissues, especially mucous membranes. Needed as part of visual purple in retina of eye.	Xerophthalmia (dry cornea, no tear secretion), phrynoderma (toad skin). Night blindness.
B – "complex" (water soluble) (i) Thiamine(B_1) $(C_{12}H_{17}ON_4S)$, (antineuritic).	Yeast, germ of cereals especially, wheat, peanuts, other leguminous seeds, egg yolk, liver, and lean pork.	Needed for carbohydrate metabolism. Thiamine Pyrophosphate is "co-carboxylase" which catalyzes metabolism of pyruvic acid to acetaldehyde and CO_2. (Stimulates root growth in plants).	Beriberi (on diet high in polished rice) Loss of appetite, with loss of "tone" and reduced motility in digestive tract. Cessation of growth.

Name, formula and principal effect	Important sources	Physiological functions	Result of deficiency or abscence (in man except as noted)
(ii) Riboflavin (B_2) ($C_{17}H_{20}O_6N_4$)	Green leaves, milk, eggs, liver, yeast.	Essential for growth : forms lprosthetic group of FAD enzymes concerned with intermediate metabolism of food and electron transport system.	Cheilosis (inflammation and cracking at corners of mouth). itiching and burning of eye, soreness of tongue.
(iii) Nicotinic acid or Niacin ($C_6H_5O_2N$) (antipellagric)	Green leaves, wheat germ, egg yolk, meat, liver, yeast.	Forms active group of Necotinamide adenine dinucleotide (NAD), which functions in dehydrogenation reactions.	Pellagra in man and monkeys.
(iv) Folic acid ($C_{19}H_{19}O_6N_7$)	Green leaves, liver, soyabeans, yeast, egg yolk.	Essential for growth and formation of blood cells; coenzyme involved in transfer of single-carbon units in metabolism.	Anemia (hyperchromic macrocytic) and sprue in man. Nutritional cytopenia in monkeys.
(v) Pyridoxine (B_6) ($C_8H_{12}O_3N$)	Yeast, cereal grains, milk, liver.	Present in tissues as pryidoxal phosphate which serves as a coenzyme in transmination and decarboxylation of amino acids.	Causes convulsions in children.
(vi) Pantothenic acid -($C_9H_{17}O_5N$)	Yeast, cane molasses, peanuts, egg yolks, milk, liver.	Forms coenzyme-A, which catalyzes transfer of various carboxylated groups.	Dermatitis in chicks and rats. Graying of fur in black rats.
(vii) Biotin ($C_{10}H_{16}O_3N_2S$)	Yeast, cereal grains, cane molasses, egg yolk, vegetables, fresh fruits.	Essential for growth. Functions in CO_2 fixation and fatty acid synthesis in bacteria.	Dermatitis with thickening of skin in rats and chicks. Perosis in birds.
(viii) B_{12} ($C_{63}H_{90}N_{14}O_{14}PCo$)	Liver, fish, meat, milk egg yolk, oysters, backteria and fermentations of Streptomyces.	Formation of blood cells growth, coenzyme involved in transfer of methyl groups and in nucleic acid metabolism.	Pernicious anemia. Slow growth in youngs.
Vit. C, or Ascorbic acid ($C_6H_8O_6$) (Water soluble)	Citrus fruits, tomatoes, vegetables; also produced by animals (except primates and guinea pigs)	Maintains integrity of capillary walls; involved in formation of "intercellular cement".	Scurvy (bleeding in mucous membranes, under skin, and into joints).
Vit. D ($C_{28}H_{44}O$), (antirachitic fat-soluble)	Fish-liver oils, especially tuna, less in cod; also from exposure of skin to ultraviolet radiation.	Regulates metabolism of calcium and phosphorus; needed for normal growth and mineralization of bones.	Rickets in young (bones soft, yielding, often deformed). Osteomalacia (soft bones), especially in women of brient.
Vit. E or Tocopherol ($C_{29}H_{50}O_2$), (antisterility-fat-soluble)	Green leaves; wheatgerm oil and other vegetable fats.	Antioxidative	Sterility in male fowls and rats; degeneration of testes with failure of spermatogenesis. Death of embryos. "Suckling paralysis" of muscular dystrophy in youog animals
Vit. K ($C_{31}H_{46}O_2$) (antihemorrhagivc fat-soluble)	Green leaves, also certain bacteria as those of intestinal flora.	Essential to production of prothrombin in liver, necessary for blood clotting Functions in CO_2 fixation and fatty acid synthesis in bacteria.	Blood fails to clot.

CLASSIFICATION OF FOOD ON THE BASIS OF FUNCTIONS

On the basis of functions the food, we normally eat can be classified into following three groups :

(a) **Energy Giving Foods** - These foods are rich in carbohydrates and fats. They provide energy and heat to out body. Examples : cereals, tubers, sugars, fats and oils.

(b) **Body Building Foods** - These foods are rich in proteins, minerals and fats. They provide main constituents of nutrients which are necessary for body building and repair of tissues. Examples: pulses, beans, milk products, fish, eggs and meat etc.

(c) **Protective foods** - These are rich in vitamins along with other nutrients. This group of food protects us from diseases as well as help our body in utilization of other nutrients. Examples: vegetables.

Food items generally consumed are cereals, pulses, vegetables, tubers (potato and sweet potato), fruits, milk and milk products, meat, fish, eggs, sugar, ghee and oils. These items, if collectively considered, contain all the nutrients required for the growth, development and maintenance of body. But not a single food item contains all the desired nutrients and in required proportions. Therefore, for good health it is necessary to include variety of food items in the diet.

For proper growth and development and maintenance of good health, the nutrients are to be taken in sufficient quantity and in proper proportion. An unbalanced diet may lead to ill health and several bodily disorders.

BALANCED DIET

A diet is said to be balanced diet when it provides proper amount and proportion of calories, proteins, minerals and vitamins according to daily requirement. A typical balanced diet for an Indian adult is suggested as follows :

Cereals	400 gm	Fruits	85 gm
Pulses and nuts	85 gm	Milk and milk products	124 gm
Leafy vegetables	114 gm	Sugar and jaggery	57 gm
Other vegetables	85 gm	Flesh food	125 gm
Root vegetables	85 gm	Oils and fats	57 gm

The nutritive value of such a balanced diet is about 3,000 calories. This diet contains 90 gm protein, 90 gm fat and 450 gm carbohydrates, i.e. protein, fats, and carbohydrates in the ratio of 1 : 1 : 5. Besides these three nutrients, it contains adequate amount of vitamins and minerals.

FOOD REQUIREMENTS

The food requirements of a person are indicated by the measure of calorie. One gramme of proteins and carbohydrates yield about 4 calories and one gramme of fats yield about 9 calories. The total requirement of calories depends upon factors such as age, type of work and state of nutrition of an individual. Children between the age of 4-5 years require 1500 calories and more protein in their diet for growth. A boy between the age 13 to 15 years needs 2500 calories while a girl of same age (13 to 15 years) 2200 calories. A person of 16 to 18 years or above, doing normal daily work needs 3,000 calories while a labourer 3,900 calories. A shopkeeper or a office going person needs only 2400 calories.

Proteins - The need of proteins also depends upon the age and state of the individual. The protein requirement varies for an infant, children, adolescent, an adult, a pregnant lady or lactating mother and a patient. The protein requirement for persons of different age groups is shown in the above figure.

Minerals: The requirement of minerals also depends upon the age, sex and nature of work. For example, an infant needs more calcium, about 0.5-0.6 gm than an adult who needs only 0.4 gm calcium per day. An adolescent girl needs more iron and other minerals than a man working in the normal environment.

Vitamins: Various vitamins are needed in different quantities. Their requirement depends upon the nature of food one takes and state of physical health. For example, requirement of vitamin B-complex increases when we take more carbohydrates and fats. Patients are also given vitamin B-complex and also vitamin C along with prescribed medicines.

It is not difficult to procure a balanced diet if one knows the nutritive value of food items. Raw vegetables and fruits provide more nutrients than boiled or fried ones. Similarly, germinating gram

Table 17.8: Balanced Diet for Adult (Woman)

Food Items (in gms)	Sedentary		Active		Very Active		Additional Amount	
	Veg.	Non-veg.	Veg.	Non-veg.	Veg.	Non-veg.	During Pregnancy	During Lactation
Cereals	300	300	350	350	475	475	+50	+100
Pulses	60	45	70	55	70	55	—	+10
Leafy vegetables	125	125	125	125	125	125	+25	+25
Other vegetables	75	75	75	75	100	100	—	—
Underground root & stem	50	50	75	75	100	100	—	—
Fruits	30	30	30	30	30	30	—	—
Milk	200	100	200	100	200	100	+125	+125
Fats & oils	30	35	35	40	40	45	—	+15
Sugar (Gur)	30	30	30	30	40	40	—	—
Meat & fish	—	30	—	30	—	40	+10	+20
Egg	—	30	—	30	—	30	—	—
Ground Nut	—	—	—	—	40*	40*	—	—

* In place of ground nut one can take additional 30 gms. of fats or oils.

seeds provide good quality protein and vitamin B-complex and vitamin C. Fermentated wheat flour or pulses flour products are better than simple chapatis and dal.

Undernutrition: In a developing country like India, where over-population and unemployment are the major problems, poor people are unable to provide sufficient food to their family for want of purchasing power. They remain under-fed. This consumption of less quantity of nutrients (less calories) then required is known as **undernutrition.**

Symptoms of Inadequate Nourishment:

Undernourishment causes physical and mental retardation.

Physical Retardation: (i) Poor physique, (ii) Poor development of muscles and less deposition of subcutaneous fat, (iii) More susceptible to infections, (iv) Dry skin and dull look.

Mental Retardation: (i) Lack of concentration and restlessness, (ii) Poor nervous and muscular coordination, (iii) Poor social adjustment due to low mental development.

A child who is 10 per cent or more below normal or standard weight for height and age is considered to be undernourished.

MALNUTRITION

Lack of deficiency of one or more of the essential nutrients in the diet is known as malnutrition. For example, some children are provided with food containing more carbohydrates and fats but there is lack of protein nutrient. Such children will shown inactivity, dullness, low working efficiency and less mental growth.

Malnutrition at the early age of childhood can cause certain irreversible damage to the brain. Malnutrition in later years may affect the size, weight and mental development.

Causes of Malnutrition in India

(i) **Poverty :** Due to poverty a large section of population cannot afford a balanced diet.

(ii) *Ignorance:* Most of the people do not know the importance of nutrition and substitutes for expensive food items.

(iii) **Food Shortage :** In general.

(iv) **Faulty Food Disstribution:** Some of the regions of our country have enough food production but other regions have less production. Therefore, there is a need of proper food distribution.

(v) **Faulty Habits:** Sometimes malnutrition is due to faulty food habits.

Deficiency Diseases Due to Protein Caloric Malnutrition

The children between the age group of one to three years are mostly affected by this. Protein-

Table 17.9 : Balanced Diet for Children of Different Age Groups

Food Items (in gms)	1 - 3 yrs.		4 - 7 yrs.		7 - 9 yrs.		10 - 12 yrs.	
	Veg.	Non-veg.	Veg.	Non-veg.	Veg.	Non-veg.	Veg.	Non-veg.
Cereals	150	150	200	200	250	250	320	320
Pulses	50	40	60	50	70	60	70	60
Leafy Vegetables	50	50	75	75	75	75	100	100
Other Vegetables	30	30	50	50	50	50	75	75
Fruits	50	50	50	50	50	50	50	50
Milk	300	200	250	200	250	200	250	200
Oils & Fats	20	20	25	25	30	30	35	35
Meat-Fish-Egg	—	30	—	30	—	30	—	30
Sugar/Gur	30	30	40	40	50	50	50	50

caloric malnutrition is due to following two reasons: (a) Lack of protein or carbohydrates or both (b) Less intake of protein than carbohydrate. Protein-caloric malnutrition (PCM) may cause Marasmus and Kwashiokor deficiency diseases.

Marasmus

Children who do not take sufficient food suffer from this disease. It is caused due to deficiency of both proteins and carbohydrates, i.e. insufficient caloric intake.

Symptoms (i) The child has shrivelled appearance.

(ii) Muscles are not well developed and body has a little fat deposition. Due to these reasons the skin is thrown into folds.

(iii) The face appears thin.

(iv) Eyes are sunken.

(v) Child becomes more susceptible to infections.

The child may recover if provided with sufficient food containing adequate protein and carbohydrate nutrient. Long suffering with this deficiency disease may cause irreversible retarded mental growth.

Kwashiokor

It is also caused by protein calorie malnutrition. The major cause is severe protein malnutrition. For normal growth and at least 1 gram of protein per kg body weight in adult and about 2 g to 3.5 g of proteins per kg body weight in actively growing children should be taken daily with food.

Symptoms (i) Stunted growth and loss of appetite in children.

(ii) Protruding bellies and bulging eyes.

(iii) Thin match stick legs, which sometimes become swollen.

(iv) Change in the colour of skin and hair.

DEFICIENCY DISEASES DUE TO LACK OF PROTECTIVE FOOD

The minerals and vitamins protect us from diseases. Deficiency of any of the mineral or vitamin causes deficiency disease. These are given below -

Mineral Deficiency

The diseases caused by deficiency of calcium, iron and iodine are common in India.

Deficiency of Calcium - The daily requirement of calcium is about 1 gm. This is available in milk, milk products, green leafy vegetables and cereals like ragi. This deficiency is associated with deficiency of vitamin D.

Symptoms - The deficiency of calcium causes poor bone formation, dental carries and disfunction of muscles.

Deficiency of Iron - The daily requirement is about 20 to 30 mg. It is found in cereals, pulses, meat and leafy vegetables.

Symptoms - The deficiency of iron causes anaemia. The body becomes pale, the man feels fatigue and has no appetite. Anaemia can be diagnosed by testing the red blood corpuscles in blood.

Deficiency of Iodine - Deficiency of iodine is more prevalent in northern hilly regions of India, due to lack of iodine in drinking water.

Symptoms - Deficiency of iodine causes goitre. The person suffering from goitre has enlarged

thyroid glands and protruded eyes. Such individual has retarded growth and mental development.

Deficiency of Vitamins - The deficiency of various vitamins causes various specific diseases. Most common deficiency diseases prevalent in India are due to deficiency of vitamin A, B-complex and vitamin C.

Vitamin A Deficiency - Vitamin A deficiency causes two diseases - Xeropthalmia and night blindness. Vitamin A is available in all vegetables, yellow fruits, tomatoes, ghee, butter, milk, yellow of eggs and fish oil. The daily requirement of vitamin A in an adult is 3000 to 4000 I.U.

(i) **Xeropthalmia** - It is a disease of the eye in which the tear glands of the eye stop working and in severe cases even lead to dryness, bacterial growth and ulceration of cornea. If the disease is not treated properly it may lead to blindness.

(ii) **Night Blindness** - It is a disease in which the person is unable to see in dimlight.

Symptoms- In addition to the above, the person suffering from vitamin A deficiency, may have dry, scaly skin and the epithelial lining of the internal organs of body cavity may get injured.

Vitamin B Complex - In this group 12 members $(B_1, B_2, B_6, B_{12}, \text{etc.})$ are present. They have practically nothing in common except that they often occur together.

(i) **Vitamin B_1 Deficiency** - The deficiency of vitamin B_1 results in digestive upsets, loss of appetite and nervous disorders which lead to a paralytic disease called as Beriberi. Vitamin B_1 is available in yeast, superficial layers of the grains, groundnuts, unmilled pulses etc. An adult requires 1-2 mgs of vitamin B_1 daily.

Symptoms- The common symptoms are retarded growth, loss of appetite and weight, weakness, palpitation, nervous disorders, early fatigue and defective digestion.

(ii) **Vitamin B_2 Deficiency** - Its deficiency causes itching and burning of the eyes and inflammation of the tongue. This vitamin is available in milk, milk products, green vegetables, yeast, eggs, liver and meat. An adult requires about 1.4 mg of this vitamin daily.

Symptoms - Its common symptoms are retarded growth, redness of the eyes, dimness of the vision, soreness of the tongue.

(iii) **Nicotinic Acid Deficiency** - It causes nervous and mental disorders and pellagra. It is available in wheat, gram, potatoes, superficial layers of grain, pulses, nuts, tomatoes, leafy vegetables, and meat. Average daily requirement of this vitamin is 10 mg.

Symptoms- Smooth and red tongue, digestive and mental disorders, pigmented scaly skin (pellagra).

(iv) **Vitamin B_6 Deficiency** - It causes convulsions in children. It is available in green vegetables, meat and liver.

(v) **Vitamin B_{12} Deficiency** - The deficiency of this vitamin causes pernicious anaemia. It is necessary for the maturation of R.B.Cs. It is found in milk, meat and liver. Daily requirement of this vitamin is 1-2 mg.

(vi) **Folic Acid Deficiency** - Its deficiency causes anaemia in infants and pregnant women. It is readily available in green vegetables, liver and pulses. Its daily requirement is 5 mg.

Vitamin C Deficiency - The deficiency of this vitamin causes scurvy. Vitamin C is readily available in citrus fruits, amla, tomatoes, leafy vegetables, potatoes, sprouted grains. The daily requirement of this vitamin is 50 mg.

Symptoms - Bleeding gums, tendency for haemorrhages, and poor wound healing.

Vitamin D Deficiency - The deficiency of this vitamin causes rickets.

Symptoms - Softness and bending of bones, (rickets), poor development and decay of teeth, osteomalcia.

QUESTIONS

1. What juice is secreted by the digestive glands of stomach? Name the enzymes present and their role.
2. Which enzyme is present in the saliva of man? What is its role? Name one mammal where this enzyme is absent.
3. Name the enzymes that digest protein in what medium these function?

4. What are the end products of protein digestion?
5. In which part of alimentary canal fats are digested?
6. Name the inactive forms of pepsin and trypsin. Why these are secreted in inactive form?
7. What changes inactive trypsinogen into active trypsin?
8. What is the function of trypsin?
9. Where does digestion in Amoeba takes place?
10. Name the enzymes present in the pancreatic juice or intestinal juice.
11. What activates pancreatic juice and what controls secretion of this juice?
12. Is digestion a physical or chemical action?
13. Name the layer of stomach which contains gastric glands. Name the types of cells present in gastric glands and their secretions.
14. Where is food digested in Amoeba?
15. Where is bile juice formed? Discuss its importance in digestion.
16. What is function of lipase?
17. What part of alimentary canal secretes salivary amylase?
18. Which part of the alimentary canal has alkaline medium?
19. Name the organs of ingestion in Amoeba and Paramecium.
20. Fill in the blanks:
    (i) The end product of carbohydrate digestion is ....
    (ii) Animals that feed on microscopic organisms are called ....
    (iii) .... exhibit autotrophic mode of nutrition.
    (iv) The organisms that feed on dead and decaying organic matter are ....
    (v) Sanguivorous animals like mosquito feed on ....
    (vi) .... enzyme activates inactive trypsinogen into trypsin.
    (vii) .... shows both intercellular and intracellular digestion.
    (viii) Digestion of food in the gastrovascular cavity of Hydra is called .... digestion.
    (ix) The enzymes that helps in the digestion of food are .... in nature.
    (x) .... is secreted by the pancreas.
    (xi) The .... teeth are well developed in carnivorous animals.
    (xii) Both pepsin and trypsin are protein digesting enzymes but pepsin works in .... medium and trypsin acts in .... medium.
21. Substitute each phrase with a proper term.
    (i) An enzyme that causes curdling of milk in the alimentary canal ....
    (ii) The juice released by the intestinal wall ....
    (iii) The action of bile juice on fats ....
    (iv) Digestion of food inside the food vacuole in a cell ....
    (v) The process of capturing and intake of food ....
22. What is heterotrophic nutrition?
23. Why there is need for the process of digestion?
24. What is the role of pepsin and lipase in the digestion of food?
25. Why does intestinal wall have so many villi?
26. Why plants do not have an alimentary canal?
27. What is cyclosis and how it occurs in Paramecium?
28. How is bile juice helpful in digestion, though it contains no digestive enzymes?
29. Both pepsin and trypsin act on proteins. How does their action differ?
30. Explain the difference between intercellular and intracellular digestion.
31. Differentiate between
    (i) Carnivorous and insectivorous
    (ii) Auxotrophic and heterotrophic nutrition
    (iii) Egestion and ingestion.
    (iv) Coprozoic and Omnivorous
    (v) Microphagous and macrophagous
    (vi) Pinocytosis and diffusion.
32. Describe different modes of ingestion in animals.
33. What is the advantage of having a long intestine?
34. Describe fate of carbohydrates in human body.
35. Can cellulose be digested in man?
36. How and where are carbohydrates, proteins and fats digested?
37. What is digestion? Describe digestion of proteins in the alimentary canal.
38. In a tabular form, give an account of various enzymes required in digestion in your body. Mention their sources as well.
39. Draw diagram only to illustrate
    (i) Ingestion in Amoeba and Paramecium.

(ii) Alimentary canal of man.

(iii) Stomach of a herbivorous mammal.

40. Name two water soluble vitamins and their deficiency diseases.
41. Why calcium is needed by human body?
42. Which nutrient is described as body building food?
43. Which vitamin is called anti-rickets?
44. Name the disease caused by the deficiency of iodine in food.
45. Which component of food is essential for both body-building and protection?
46. How much energy is released by the oxidation of 1 gm. molecule of carbohydrate?
47. Which is the basic energy yielding compound utilized by the body cells?
48. What happens to the extra glucose in the body when carbohydrate intake is high?
49. Which food stuff yields the maximum amount of energy on complete combustion and how much?
50. What is the normal blood glucose level in man?
51. Coin one word for each of the following sentences:
    (i) Food needed in very small quantity, with no energy value but essential for resistance against diseases ....
    (ii) A macromolecule formed by the linking of hundreds or thousands of amino-acids ....
    (iii) Compound of glycerol and fatty acids which are liquid at room temperature ....
    (iv) Disease caused due to deficiency of iron ....
    (v) Antiscurvy vitamin ....
52. Name the disease caused by deficiency of iron.
53. Which mineral is required for healthy growth of bones and teeth?
54. Give uses of vitamin A.
55. Name the protein found in blood and egg.
56. Write true or false :
    (i) The main energy yielding foods are carbohydrates and fats.
    (ii) Minerals are body building food.
    (iii) Vitamin C is destroyed on heating.
    (iv) One gram molecule of fat on oxidation, releases 7 kcal energy.
    (v) Herbivorous do not require vitamins.
    (vi) Fats are nonessential component of food.
57. Fill in the blanks :
    (i) The salts that are deposited in the ground substance of bone are .... and ....
    (ii) .... is required in the transmission of nerve impulse.
    (iii) Carbohydrates and fats are .... yielding food.
    (iv) Animal starch stored in muscles and liver is ....
    (v) .... and .... are examples of polysaccharides.
    (vi) Fats are compounds of .... and ....
58. What is peptide bond?
59. Which are second grade energy yielding food?
60. Which are called high quality proteins?
61. What are the energy reserves in animals?
62. Why vitamins are important for animals even when they do not produce energy?
63. What will happen if food of a person has a regular deficiency of iodine and why?
64. What are the three groups of food based on their nutritional value?
65. Give important functions of fats.
66. What role proteins play in our body?
67. Name the nutrients in a diet consisting of carrot and bread.
68. Why do we need food?
69. Why proteins are described as body-building food?
70. What is the importance of cereals and pulses in our food?
71. Why animal proteins are described as high quality proteins?
    OR
    Why animal proteins are considered superior to plant proteins?
72. What do you mean by nutrition? Describe organic component of food?
73. Name the minerals required by the human body. Mention any four of their functions.
74. Mention the roles of following in human body—
    (i) Water   (ii) Proteins
    (iii) Carbohydrates   (iv) Vitamin-B Complex.

□ □

RESPIRATION

All living organisms require energy for various life processes. The energy is released in steps from continuous break down of food stuffs. It is temporarily stored as ATP and is used by the cells in this form only. '*The biochemical process which involves degradation of organic compounds in stepwise oxidation with the release of energy, inside the living cells at body temperature*' is called respiration.

AEROBIC AND ANAEROBIC RESPIRATION

Aerobic Respiration

In *aerobic respiration* food stuffs (basically glucose) are oxidized in presence of oxygen. There is complete oxidation of carbohydrates producing *carbon-dioxide, water* and *energy*.

$$C_6H_{12} + 6 + 6CO_2 \rightarrow 6CO_2 + 6H_2O + \text{energy 686 kcal}$$
(1 mol. Glucose)   (38 ATP)

In complete oxidation of one gram molecule of glucose 686 kcal of energy is produced. It is stored in 38 ATP molecules and is utilized according to the need of cell.

Anaerobic Respiration

When the respiratory substances are broken in the complete absence of oxygen, the respiration is said to be *anaerobic respiration*. In anaerobic respiration, there is incomplete degradation of substrate (*e.g.* glucose) and release of carbon dioxide, organic compounds such as ethyl alcohol, lactic acid etc. and energy (54 k cal). The energy released during this process is much less than the aerobic respiration.
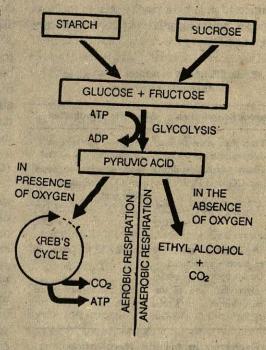
Fig. 18.1 Aerobic and anaerobic type of respiration.

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2C_2H_5OH + 2CO_2$$
(Glucose)   (Ethyl alcohol)
                    + energy (54 k cal)
                    (2 ATP)

Usually, anaerobic respiration occurs in the deep seated tissues of plants and animals, in germinating seeds, in fruits and microbes.

Anaerobic respiration occurs in some multicellular animals also, such as intestinal parasites like tapeworm, round worm, hook worm and in liverflukes. Anaerobic respiration also occurs in skeletal muscles during vigorous movements, when these do not get immediately

as much oxygen as is necessary. During anaerobic respiration, muscles produce *lactic acid* that accumulates causing *muscle fatigue*. It is gradually removed by blood and is oxidised aerobically in liver cells and cardiac muscles. *Red blood corpuscles* also respire anaerobically because these lack mitochondria. Certain micro-organisms e.g. fungi (yeast) and bacteria, utilize the substances present outside the cell as respiratory substance during anaerobic respiration. This type of anaerobic respiration is called **fermentation.**

Fermentation is most readily seen in molasses and grapes, where sugar is broken down into ethyl alcohol and CO_2.

Table. 18Differences between Aerobic and
Anaerobic Respiration

Arotic Repspiration	Anaerotic Repspiration
1. Takes place in the presende of oxygen.	Oxygen is not required.
2. Glucose is broken down into CO_2 and H_2O. $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$	Glucose is broken down into CO_2 and alcohol or lactic acid. $C_6H_{12}O_6 \rightarrow C_2H_5OH + CO_2$
3. 38 ATP per one gram mole of glucose are formed.	Only 2 ATP are produced.
4. Occurs both in cytoplasm (glycolysis) and in the mitochondria 'Krebs cycle).	Takes place only in the cytoplasm.

Gas Exchange in Aerobic Respiration

All aerobes need oxygen for metabolism and must dispose of resulting carbon dioxide. *Oxygen is taken from the environment by diffusion and CO_2 generated during cellular respiration diffuses out into the environment.* The air contains 21% oxygen but water holds only 0.7%. Therefore, for terrestrial organisms availability of oxygen in air is more than for aquatic animals in water.

Gas Exchange Mechanisms

Animals obtain oxygen in five ways:

1. From water or air through moist body surface directly into the body as in *Amoeba.*
2. From air or water through the thin body wall to blood vessels e.g. Earthworm.
3. From air through spiracles to a system of air tube-tracheae to tissues and tissue cells or from

water through tracheal gills e.g. insects.
4. From water through gill surface to blood vessels and then to tissue cell (e.g. fishes and amphibians.
5. From air through moist lung surfaces to blood vessels and from there to tissue cells.

1. Gas Exchange in Unicellular Organisms— Among aquatic unicellular organisms like *Amoeba, Paramecium* etc., the unicellular body is in direct contact with the external environment. Therefore, oxygen dissolved in water diffuses into the body through general body surface and carbon-dioxide diffuses out into the surrounding water.

The surface area: Volume ratio is large enough so that simple diffusion of gases across general body surface of animals is adequate to take care of its respiratory needs. The oxygen concentration also described as partial pressure of oxygen within the cell is always lower because of its utilization in oxidation of food stuff by mitochondria.

Gas Exchange in Multicellular Organisms

Among multicellular organisms, the ratio of surface to volume is smaller. Many of their cells, tissues and organs are located too deep within the body to carry on adequate gas exchange with the environment by diffusion alone. For this purpose cells in the interior of an organism bathe in an ECF, lymph or blood. This fluid supplies oxygen to tissue cells and removes CO_2. In turn, its oxygen concentration is replenished by fresh supplies of oxygen from the surrounding environment.

Thus in multicellular organism exchange of gases is carried out in two phases or at two levels—

1. External respiration or Exchange at organismic level—It is exchange of gases between environment and respiratory organ. It includes uptake of oxygen from the surroundings and elimination of CO_2 into the surroundings.

2. Internal respiration—In involves exchange of gases between body fluids and tissue cells. It is completed in three steps—

1. Oxygen uptake by tissue cells from blood through ECF
2. Tissue oxidation (oxidation of food stuffs)
3. Elimination of CO_2 from tissue cells.
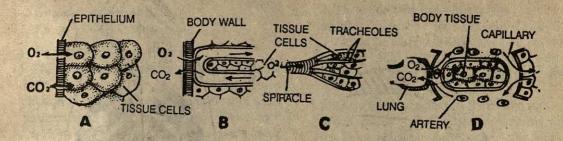
Fig. 18.2 Mechanism of gas exchange in multicellular animals.

2. These must be kept moist so that O_2 and CO_2 can be dissolved in water for diffusion.

3. These must be highly vascular.

Types of Respiratory Organ Found in Animals

Following four types of respiratory structures are used by mammals—

1. Body surface   2. Tracheae tubes
3. Gills   4. Lungs

Basic Characteristics of Respiratory Organs

In large more complex forms, specialized respiratory structures are required. To bring atmospheric air and body blood in close contact so that oxygen from air can diffuse into blood and CO_2 can diffuse into the air. Therefore, these must have thin walls so that diffusion can occur

1. General body surface—Multicellular animals that use general body surface for gas exchange by simple diffusion are porifers, coelenterate, flat worms and many annelids. These animals are comparatively inactive and due to low metabolic rate their oxygen need is much less. In some forms the surface: volume ratio is increased by flattening of body (flatworms) or by the development of flat surfaces (mesenteries) inside the body (sea anemones).

In these forms, gases diffuse through the epithelial cells of outer body covering and thence to cells situated deeper in the body.

In worms and leeches, gaseous exchange occurs through skin and is called *cutaneous respiration*.
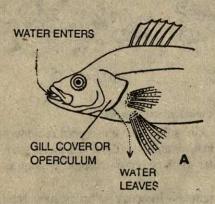
Their skin is thin, moist and permeable to gases. Even in toads and frogs the skin is moist and highly vascular to carry out cutaneous respiration.

2. Tracheae—Insects, centipedes, some arachnids and *Peripatus* have developed dry and impervious integument to minimise water lose from body surface. Cutaneous respiration is out of question. Therefore, these have a complex system of fine branched air tubes, called *tracheae*. These develop as ingrowth of the bodywall and are lined with chitin.

Each trachea communicates with the exterior. Its opening on the body surface is called *spiracle* or *stigmata*. The spiracles have *valves* and *hair* to regulate water loss and filter the air. The fine branches of trachea are called *tracheoles* which form a sort of capillary network in the intercellular spaces of tissue, bringing air deep within body, near enough to each cell. The gas exchange takes place directly between air and tissue cells through tracheal system. The end of tracheoles is filled with fluid through which oxygen and carbon dioxide diffuse to and form the adjacent tissue cells.

Air enters the tracheal tubes through spiracles by the relaxation of abdominal muscles. Contraction of abdominal muscles drives air out from tracheal system through spiracles. In large and active insects, the movement of abdomen is assisted by rhythmic movements of tracheal tubes newing the air.

3. Gills—Gills are respiratory organs of aquatic animals. These are moist, thin structures that extend from the body surface. These are richly supplied with blood and their outer surface is

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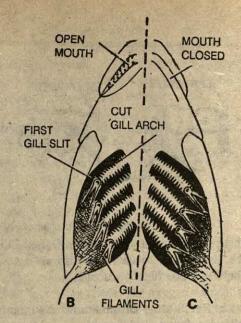
Fig. 18.3 The Gills. (A) The organs of respirations in fish (B) Breathing mechanism in fish. (i) During inspiration (ii) During expiration.

exposed to water. Gills are found in some annelids, crustaceans, molluscs, echinoderms, fishes and amphibians. These have different structure and appearance. The gills may be *external* exposed directly to the environment (in cartilaginous fishes and frog tadpole); or these may be internal. Internal gills are found in bony fishes, where these are protected by external bony plate, the *operculum*. Movements of operculum help to pump water in through mouth.

In bony fishes, each gill bears rows of comb-like soft, thin *gill-filaments*. Each gill-filament is formed of many flat-parallel membrane-like *gill-lamellae*. These present large surface to water. Each gill lamella has cilia on its outer surface and carries fine blood capillaries. The blood flows in the capillaries of gill-lamellae in a direction opposite to the flow of water over the lamellar surfaces. Exchange of gases occurs between surrounding water and blood within lamellae. The oxygenated blood transports oxygen to the interior tissues of body.

The same blood picks up CO_2 from the interior tissue and transports it to the gills, from where CO_2 diffuses out into surrounding water.

This system has three basic but essential parts—

1. A *circulating fluid* which transport gases to and from tissue cells and gills.

2. *Gill* which provide surface for the exchange of gases between circulating fluid and water.

3. A mechanism for a continuous *supply of oxygenated water* over the gills.

The circulating fluid is blood. Usually it contains *haemoglobin*, the respiratory pigment that helps in the transport of oxygen by forming temporary compound **oxyhaemoglobin.**

Supply of oxygenated water to gills is maintained

1. by rhythmic beating of cilia present on the exposed surface of gill filaments.

2. by opening and closing of mouth and buccal cavity which force water through the gill arches.

3. by the movement of opercular fold.

4. **Lungs**—Lungs are developed as ingrowths of body surface from the wall of pharynx, adapted for aerial breathing. These are found in terrestrial animals such as arachnids, some molluscs, lung fishes, amphibians, reptiles, birds and mammal.

RESPIRATORY ORGANS IN MAN

The respiratory organs can be separated into (A) *accessory* or *conducting organs* or the *air passages* (B) *principle respiratory organs.* These are :

1. Nostrils and Nasal Passages ⎫
2. Larynx ⎪
3. Trachea ⎬ **Conducting organs**
4. **Bronchi and bronchioles** ⎪
5. **Lungs—Main organs** ⎭

1. Nostrils and Nasal Passages

The nasal passages are paired tubes in the roof of buccal cavity. The *palatine bones* form a partition between the two, forming floor of nasal passages and roof of buccal cavity. These open outside by two *nostrils* or *anterior nares* and inside into the nasopharynx by two *posterior nares* or *choanae*. The nasal passages are separated all along their length by a *septum*. Its anterior portion is cartilaginous and posterior bony. Each nasal passage can be separated into two parts.

(i) **Vestibule**—It is the broad anterior part of nasal passage, which is connected with the nostrils.

(ii) **Nasal chamber**—It is the main portion and has 3 flat turbinal bones, sticking out from the outside wall into its cavity.

All the inner surfaces of nasal passages are lined with thin and moist mucous membrane. Its cells are ciliated and secrete *mucus*, a watery fluid into the nasal chambers. The mucous membrane of ethano-turbinal region is sensory epithelium. It is called *Schneiderian membrane*. Its cells are *olfactory*.

Functions—The long nasal passages serve the following functions—

(i) Air passages act as passageways for air going to and from the lungs.

(ii) **Act as filter**, because large sized bacteria, spores and dust particles in the inhaled air become entangled between the hairs of vestibules and removed. Small particles of sand become entangled in mucus. The contaminated mucus is swept into pharynx.

(iii) **Cilia** of nasal epithelium vibrate in the direction opposite to the inhaled air and keep the passage clean.

iv) **Act as air conditioners** i.e. the muscus and rich blood supply to nasal passages warm or cool the inhaled are and bring it at body temperature before it enters the lungs.

(v) Mucus makes the air moist.

(vi) The **olfactory receptors of Schneiderian membrane** detect smell.

(vii) Groups of **adenoid** *cells* that form pharyngeal tonsils kill bacteria, removed by the mucus.

2. Throat or pharynx—In pharynx the food and air tubes cross each other. The opening of air tube-trachea in the pharynx is called *glottis*. It is guarded by a cartilaginous flap, *epiglottis*. During Swallowing, epiglottis closes glottis and keeps food out of the respiratory tube.

3. Larynx or Voice box—It is the large upper part of trachea and is responsible for producing voice. It is formed of *nine cartilages*, two sets of muscles and two pairs of vocal cords. The length and tension of vocal cords is maintained by the intrinsic muscles, which also control opening and closing of glottis. The vibrations of vocal cords produce voice. The thyroid cartilage of larynx forms Adam's apple.

The larynx is covered with mucous membrane. Its folds form the vocal cords. The oedema of mucus membrane of vocal cords obstructs glottis and lead to *asphyxiation*.

4. Trachea or wind pipe—It is about 11 cm. long tube with a diameter of about 2.5 cm. It extends from larynx in the neck to bronchi in the thoracic cavity. It lies ventral to oesophagus. Its wall is supported with C-shaped *cartilaginous rings*. These prevent collapsing of trachea. The cartilaginous rings are complete in the posterior part of trachea.

5. Bronchi and Bronchioles—On entering thoracic cavity, the trachea divides into two **primary bronchi**. The right bronchus is slightly larger. The structure of bronchial wall is similar to tracheal wall except the cartilaginous rings are incomplete.

Each primary bronchus enters the lung of its side and immediately divides into *secondary* and *tertiary* or *segmental bronchi*. These branch into *bronchioles, terminal bronchioles* and then into *respiratory bronchioles*. A bronchus with its branches is described as a *bronchial tree*.

6. Alveolar sacs and Alveoli—The respiratory bronchioles finally end in *alveolar ducts*. Each alveolar duct is connected with several thin-walled *alveolar sacs*. Their wall is formed of numerous *alveoli* or *air sacs*.

Alveoli or *air sacs* are the functional units of lungs. About 300 million of them are present in

our lungs. Each alveolus is about 1 mm in diameter. Its wall is thin and elastic and is formed of single layer of simple squamous epithelium. Its

Fig. 18.5. T.S. Human Lung.

outer surface is covered with network of capillaries from pulmonary artery and vein.

Lungs—The lungs are a pair of conical, highly elastic and hollow bag-like organs that fill the pleural portion of thoracic cavity. The broad lower surface of lung that rests an the diaphragm is concave and forms the base, whereas the pointed upper margin is apex. The primary bronchus and pulmonary blood vessels enter each lung through a slit on its medial surface, called **hilum.** The right lung is larger than left. The right lung is divided into three lobes—**superior, middle** and **inferior,** while the left lung is divided into two lobes—**upper** and **lower.**

The lungs are enclosed by a double layered membrane called *pleura.* The pleural membranes are separated by a thin space filled with *pleural fluid.* The pleural membrane that covers the lungs is called **visceral pleura** and the one which lines the pleural cavity is called **parietal pleura.**

Histology of Lungs

Histologically, a lung is formed of numerous *alveoli* or *air sacs.* Around each alveolus is a network of capillaries of both pulmonary artery and pulmonary vein. The alveolar wall is formed of simple squamous epithelium.

Function of Lung—Lungs provide a very large surface for exchange of gases. Here very thin respiratory membrane of alveoli lies in contact with equally thin walled pulmonary capillaries. This enables rapid diffusion of gases between alveolar

Fig. 18.4 (A) Lungs in man, (B and C) Structure of bronchiol and alveolus
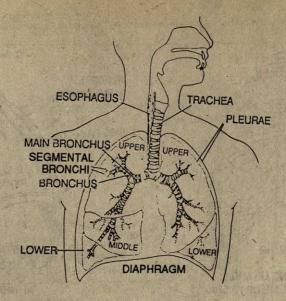
Fig. 18.6 Diagram of lungs, showing position of hear

air and capillary blood. The respiratory area provided by 300 million air sacs is estimated to be about 70 square meters.

MECHANISM OF RESPIRATION

In man and other mammals, the mechanism of respiration can be divided into

1. Pulmonary ventilation—*breathing*
2. Exchange of gases between air and blood— *External respiration.*
3. Transport of gases to and from cells—*Transport.*
4. Exchange of gases between blood and body cells—*Internal respiration.*

1. Pulmonary ventilation is the technical term for breathing. It involves two phases :

(i) Breathing in fresh air—*Inspiration*

(ii) *Exhaling or breathing out used air— Expiration.*

The movement of air in and out of the lungs is facilitated by alternate changes in intrapulmonary pressure. When atmospheric pressure is greater than the pressure within lung, air flows into lungs. This is called **inspiration.** When pressure inside lungs is more than the atmospheric pressure air moves out. This is called **expiration.** During inspiration, the **radial muscles** of diaphragm and the external **intercostal muscles** contract. This

RELAXATION OF INSPIRATORY MUSCLES
↓
DECREASE IN SIZE OF THORAX
        ELASTIC RECOIL OF LUNG TISSUE
INCREASE IN INTRATHORACIC PRESSURE
FROM ABOUT −6 TO + 4 mm Hg
↓
DECREASE IN SIZE OF LUNGS
↓
INCREASE IN ALVEOLAR PRESSURE FROM
ABOUT − 3 mm Hg TO + 3 OR 4 mm Hg
↓
PRESSURE GRADIENT FROM
ALVEOLI TO ATMOSPHERE
↓
EXPIRATION
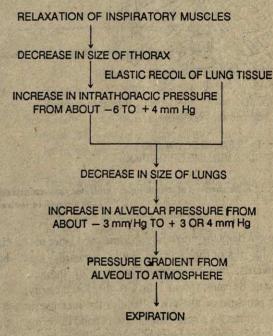
Fig. 18.7 The mechanism of normal, quiet expiration ·
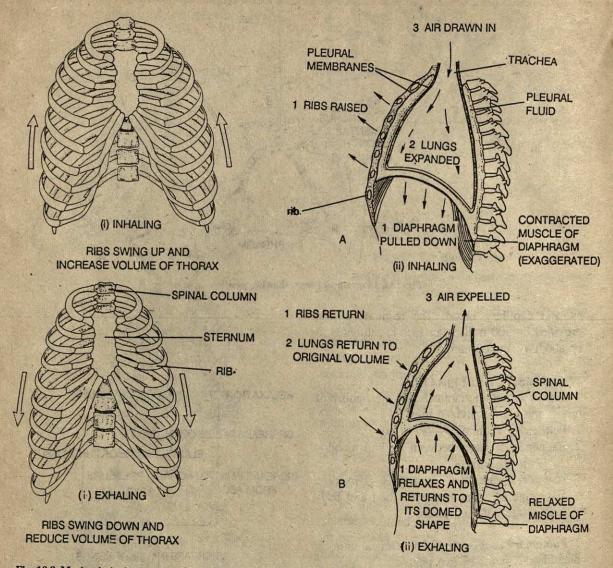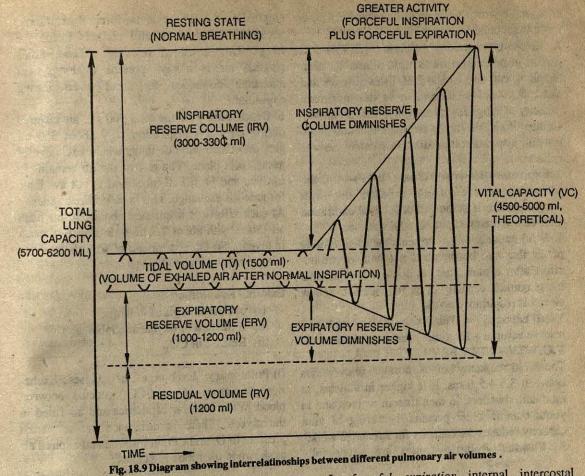
Fig. 18.8. Mechanism of breathing or respiratory movements during A. inspiration (i) in ventral view (ii) in side view and B. expiration (i) in ventral view (ii) side view.

lowers diaphragm towards abdomen and latter move the ribs or the thoracic walls outwards and upwards, thereby increase volume of thoracic cavity. Because thorax is an airtight closed cavity, the pressure of air in it falls with the increase in its volume. As a result lungs also expand lowering intrapulmonary pressure of air in the lungs below atmospheric pressure. Air from outside rushes into the lungs through nostrils. The muscles which bring about inspiration are called *inspiratory muscles.*

Expiration A is ordinarily a passive phenomenon. It includes relaxation of radial muscles of diaphram that moves diaphragm up towards thorax so that it becomes dome-shaped—(i) relaxation of intercostal muscles moves the intercostal and

RESTING STATE
(NORMAL BREATHING)

GREATER ACTIVITY
(FORCEFUL INSPIRATION
PLUS FORCEFUL EXPIRATION)

INSPIRATORY
RESERVE COLUME (IRV)
(3000-3300 ml)

INSPIRATORY RESERVE
COLUME DIMINISHES

TOTAL
LUNG
CAPACITY
(5700-6200 ML)

VITAL CAPACITY (VC)
(4500-5000 ml,
THEORETICAL)

TIDAL VOLUME (TV) (1500 ml)
(VOLUME OF EXHALED AIR AFTER NORMAL INSPIRATION)

EXPIRATORY
RESERVE VOLUME (ERV)
(1000-1200 ml)

EXPIRATORY RESERVE
VOLUME DIMINISHES

RESIDUAL VOLUME (RV)
(1200 ml)

TIME ———▶

Fig. 18.9 Diagram showing interrelatinoships between different pulmonary air volumes.

RELAXATION OF INSPIRATORY

ELASTIC RECOIL OF LUNG TISSUE

DECREASE IN SIZE OF THORAX

INCREASE IN INTRATHORACIC PRESSURE
FROM ABOUT – 6 TO – 4 MM HG

DECREASE IN SIZE OF LUNG

INCREASE IN ALVEOLAR PRESSURE FROM
ABOUT – 3 MM HG TO + 3 OR 4 MM HG

PRESSURE GRADIENT FROM
ALVEOLI TO ATMOSPHERE

EXPIRATION

Fig. 18.10. Summary of events during normal quiet expirator

thence the lateral thoracic walls inward and downward. This decreases the volume of thoracic cavity and increases pressure inside thorax as well in the lungs. This causes some air to be expelled out from lungs to outside.

In *forceful expiration* internal intercostal muscles and some abdominal muscles contract simultaneously reducing the volume of thoracic cavity more than in ordinary expiration. This pushes out larger volume of air from lungs. These muscles are called *expiratory muscles.*

The Respiratory Cycle and Rate of Respiration

A *respiratory cycle* consists of one inspiration and one expiration alternately. It is more in children and less in older persons. The *rate of respiration* is expressed in terms of *ventillation rate* and averages 12-14 times per minute in a normal resting human being.

Pulmonary Air Volumes

1. Tidal volume (TV)—It is the volume of air breathed in or out during effortless breathing in each respiratory cycle. It represents the volume of air renewed in lungs during each respiration. It is

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measured by means of a recording *spirometer*. Its value is about half a litre or 500 ml.

2. Inspiratory Reserve Volume (IRV)—If a person inspires with his utmost efforts by deep breathing can take in about 30 litres air over and above his tidal volume. This is the maximum capacity of lungs for inhaling air. This additional volume of air that can be breathed with maximum forceful inspiration it is called *inspiratory reserve volume*.

3. Expiratory Reserve Volume (ERV)—It is the additional volume of air expelled out with maximum efforts at the end of forceful expiration after he has breathed out his tidal volume.

4. Vital capacity—It represents the total volume of air that can be breathed out with maximum effort after a maximum inspiration. It represents the maximum capacity of an individual to renew air in his respiratory system.

Vital capacity = Tidal volume + Inspiratory reserve volume + Expiratory reserve volume.

V.C. = TV + IRV + ERV

The vital capacity of a normal man varies between 3.5-4.5 litres. It is higher in athletes, in mountain dwellers, in men than in women and in youth than in older persons. Lowering of vital capacity reduces the capacity for strenuous work.

5. Residual volume—Lungs are never fully emptied even after maximum forceful expiration, about 1.5 litres of air still remains inside the lungs. This is called *residual volume*. Since residual air is always present in lungs, gas exchange continues to occur even during expiration.

6. Dead space—Of the total 500 ml. air inspired during effortless inspiration only about 350 ml gets into those parts of lungs where exchange of gases takes place. The rest of the air remains in trachea, and bronchial tubes and is not available for gaseous exchange. This is called *dead space*. At each effortless inspiration about 350 ml fresh air mixes with about 2.5 litre air already present in alveoli. So there is mixing of so little fresh air with so much air already present.

External Respiration
- (i) exchange of gases in lungs,
- (ii) formation of oxyhaemoglobin, and
- (iii) Release of CO_2.

(i) Pulmonary Exchange of Gases: Exchange of gases (O_2 and CO_2) occurs between blood in the alveolar capillaries and air filled in the alveoli. There is difference in the partial pressure of O_2 and CO_2 in inspired and expired air as shown in the following tables :

Table 18.2 : Partial Pressure of Respiratory Gases

Gas	Inspired Air	Alveolar Air	Venous Blood	Arterial Blood	Expired Air
Oxygen	158	100	40	95	116
Carbon dioxide	0.3	40	46	40	32
Nitrogen	596	573	573	573	565

Table 18.3 : Percentage of Gases

Gas	Inspired Air	Alvelar Air	Venous Blood	Arterial Blood	Expired Air
Oxygen	21	13.1		19.8	16
Carbon dioxide	.4	5.3	52.7	49	4
Nitrogen	78.6	78	78	78	78

From the tables it is evident that PO_2 and oxygen concentration of alveolar air is lower than inspired air (because of its mixing with residual air in alveoli), but is higher than in the deoxygenated blood in the lung capillaries. So oxygen diffuses from alveolar air to capillary blood of pulmonary artery. The oxygenated blood of pulmonary veins has PO_2 of about 95 mm. Hg and oxygen concentration 19.8 per cent.

The deoxygenated blood of alveolar capillaries has PCO_2 46 mm. Hg and CO_2 concentration about 52.7 per cent. It is higher than the alveolar $_pCO_2$ of 40 mm. Hg. Therefore CO_2 diffuses from alveolar capillary blood to alveolar air until the oxygenated blood has $_pCO_2$-40 and CO_2 concentration to 49 per cent. Diffusion of gases occurs from higher concentration to lower concentration only in dissolved condition. For this reason mucus membrane of the inner surface of alveoli is always kept moist with **mucus.**

(b) **Formation of oxyhaemoglobin**—In mammals about 15-20 ml. oxygen is carried per 100 ml. of blood. This all is not carried in free state. Since only 2% oxygen can dissolve in 100 ml. of plasma at normal atmospheric pressure, the rest combines with the respiratory pigment, **haemoglobin,** present in the R.B.Cs. In region of high oxygen concentration haemoglobin combines with oxygen and forms a temporary compound, the oxyhaemoglobin.

$$Hb + O_2 \rightarrow HbO_2$$
Haemoglobin   Oxyhaemoglobin

There is a definite proportion of oxyhaemoglobin to haemoglobin present in the blood at any time. It depends upon the tension or partial pressure of oxygen in the blood and is represented by the **dissociation curve of oxyhaemoglobin.** At a partial pressure of oxygen of approximately 70 mm Hg, a molecule of haemoglobin becomes fully saturated and is completely converted into oxyhaemoglobin. Any increase in oxygen tension does not change the amount of oxyhaemoglobin formed.

(c) **Release of CO_2**—CO_2 in blood is always in combined state which forms bicarbonates, carbonic acid and loose carbamino compounds. These compounds are carried to the lungs, where these break down under the influence of following factors and liberate CO_2 Carbon.

(i) H_2CO_3 $\xrightleftharpoons[\text{Acidity of}]{\text{anhydrate}}$ $H_2O + CO_2$
oxyhaemoglobin

(ii) $2NaHCO_3$ $\xrightleftharpoons{}$ $Na_2CO_3 + H_2O + CO_2$
Reduction

(iii) $2HbNHCOOH$ $\xrightleftharpoons{}$ $HbNH_2 + CO_2$

The CO_2 liberated in this manner diffuses out of the capillary walls into the alveolar air.

2. Transport of Oxygen

Oxygen in combined state (oxyhaemoglobin) is carried by blood to different organs and tissues, where it is enclosed inside thin-walled capillaries.

3. Internal Respiration or Cellular Respiration

(i) **Dissociation of oxyhaemoglobin**—Inside the tissues the continuous metabolism of glucose and other substances results in a continuous production of CO_2 and utilization of O_2. Consequently, the concentration of oxygen in the tissue fluid and cells is always lower and concentration of carbon dioxide is always higher than in the capillaries. In the regions of low oxygen concentration, oxyhaemoglobin breaks down, releasing oxygen which diffuses out form the blood capillaries to the tissue fluid and from there to each and every cell.

$$HbO_2 \rightarrow Hb + O_2$$

The dissociation of oxyhaemoglobin is also controlled by the concentration of CO_2, which of course does not occur in free state but dissolves in water to form H_2CO_3 and increases acidity and thus results in the dissociation of oxyhaemoglobin.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

(ii) **Oxidation of foodstuffs**—The oxygen, which enters the cell cytoplasm oxidises the glucose or other food substances in presence of special respiratory enzymes and liberates energy breaking down the glucose into water and CO_2.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{(energy)}$$

4. Transport of CO_2

The CO_2 produced as a result of oxidation of foodstuffs diffuses out of the cell into the tissue fluid and thence into the blood of capillaries. This is transported both by plasma as well as the erythrocytes in three different conditions :

(1) **In Simple Physical Solution in the Plasma as Carbonic Acid**—As soon as CO_2 enters the blood, a part (5-10%) or about 2.7 c.c.) of it dissolves in water of 100 c.c. venous blood to form **carbonic acid.** It dissolves in plasma and is transported as simple solution.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

(2) **As Chemical Compounds**

Two types of compounds are formed with CO_2 in blood—

(a) **As Bicarbonates**—as sodium bicarbonate
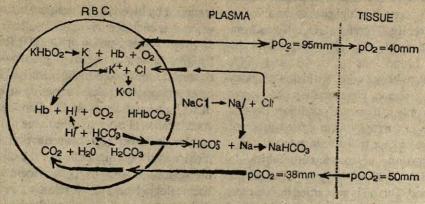
Fig. 18.11. Diagrammatic representation of the Hamburger reaction, which occurs in blood when exchange of gases occurs between blood and tissue.

$NaHCO_3$ in plasma and as potassium bicarbonate in RBC.

(i) As Bicarbonates in the R. B. Cs.

Only 5-10% of the total amount of carbon dioxide is transported as carbonic acid. In the normal course the formation of carbonic acid is a slow process and much of the CO_2 diffuses into the red blood corpuscles, where in presence of enzyme **carbonic anhydrase** the speed of carbonic acid formation is considerably enhanced. The carbonic acid ionises to form bicarbonate with the release of hydrogen ions.

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3$$

H_2CO_3 combines immediately with the potassium salt of haemoglobin.

$$H_2CO_3 + KHb \rightarrow KHCO_3 + Hb$$

Potassium   Potassium   free

haemoglobinate   bicarbonate   haemoglobin

About 80-85% CO_2 combines with sodium and potassium salts to form bicarbonates.

(ii) As Bicarbonates in Plasma
(Chloride shift or Hamburger phenomenon)

The potassium bicarbonate formed in the R. B. C. immediately ionises into—

$$KHCO_3 \quad\quad K^+ + HCO_3$$

The bicarbonate ions diffuse out in the plasma and the chloride ions from the plasma diffuse in the corpuscles. The chloride ions probably diffuse into the RBCs and combine with K^+ ions to form KCl—

$$H_2CO_3^- + 2NaCl \rightarrow NaHCO_3 + Cl^-$$

The exchange of Cl^- and HCO_3^- ions between plasma and R.B.Cs. is known as **chloride shift.**

The above reactions are reversible. H.Hb in lungs combines with oxygen and forms oxyhaemoglobin and H^+ ions are liberated. In presence of H^+ ions KCl dissociates and Cl^- ions again diffuse out into the plasma and HCO_3^- ions diffuse into the R.B.Cs. where these decompose liberating CO_2. These reactions help in maintaining a constant pH in the plasma.

(b) By phosphate buffers—The alkaline phosphate present in plasma combines with carbonic acid that is formed by the combination of H_2O and CO_2. This results in the formation of sodium bicarbonate :

$$Na_2HPO_4 + H_2CO_3 \quad\quad NaH_2PO_4 + NaHCO_3$$

(c) In combination with plasma proteins as temporary carbamino compound (NHCOOH)

(i) With plasma proteins in blood plasma— About 10% carbon dioxide forms loose carbamino compounds. The amino acids on oxidation produce two different groups, the **amino group** (NH_2) and **carboxyl group** (COOH). The amino group combines with carbon dioxide and forms carbamino proteins. These occur in 1% concentration in arterial blood and 1.1% in venous blood.

$$NH_2 + CO_2 \rightarrow NHCOOH$$

Carbamino compound
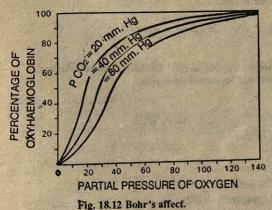
(ii) With haemoglobin in RBCs—Some CO_2 forms loose chemical compounds with proteins of blood. For example, haemoglobin combines with CO_2 to form **carbamino haemoglobin.**

$$HbNH_2 + CO_2 \rightarrow HbNHCOOH$$

Bohr's Effect

The oxygen and carbon dioxide transport are closely associated because increase in the concentration of CO_2 decreases the amount of oxygen that can be carried in the blood at a given partial pressure of oxygen. It means higher concentration of CO_2 stimulates more of oxyhaemoglobin to dissociate and release oxygen. In other words increase in the partial pressure of CO_2 accelerates the rate of oxyhaemoglobin dissociation. This fact can be represented by plotting a graph to show relationship between the partial pressure of oxygen and the percentage of oxyhaemoglobin in the blood at a given partial pressure of CO_2.

Fig. shows the oxygen dissociation curve of oxyhaemoglobin at 20, 40, 60 mm. Hg partial pressure of CO_2. This shows that increase in the partial pressure of CO_2 shifts the dissociation of curve towards right indicating that the concentration or percentage of oxyhaemoglobin in blood decreases with an increase in CO_2 concentration. This effect of CO_2 concentration on dissociation of oxyhaemoglobin was discovered by CHRISTAN BOHR and is know as **Bohr's effect** after his name.

Fig. 18.12 Bohr's affect.

RESPIRATORY DISORDERS

1. Asphyxia—It is a condition caused by interruption in the supply of oxygen to the tissue. This may be caused

(i) due to **drowning** when alveoli get filled with water

(ii) due to **pneumonia** when these become filled with tissue fluid and mucus

(iii) due to **carbon monoxide poisoning** because haemoglobin was more affimity with CO and unites with carbon monoxide instead of oxygen.

(iv) due to **cyanide poisoning** which inactivates one of the enzymes responsible for the utilization of oxygen in the cells.

2. Cough—Cough is caused by irritation of the throat and respiratory passages. The causes for coughing are (i) prolonged and excessive smoking impairs efficient functioning of various organs. The *nicotine* present in the tobacco adversely affect the nervous system, blood vessels and lungs. Heavy smoking causes lung cancer.

3. Whooping Cough—Whooping cough is caused by **Haemophilus pertussis.** It spread by discharge from the throat of infected presons. It is primarily a disease of the children.

4. Pneumonia—It is caused by bacteria—*Diplococcus pneumonia.* The lymph and mucus accumulates in the alveoli and bronchioles leading to chest congestion.

5. Tuberculosis—It is caused by a type of bacteria—*Mycobacterium tuberculosis.* It spreads through **sputum** of infected persons. Sputum is mucus expelled from trachea via mouth. It contains the mucus trapped dust particles and bacteria. The bacteria of T.B. release **tuberculin,** a toxin which causes fever, loss of weight and general weakness. The bacteria damage the lung alveoli and cause coughing The disease spreads under unhygienic conditions, dark, dingy and congested places. Tuberculosis can be curbed by BCG vaccine.

6. Influenza or flu—It is a viral disease. The common symptoms are fever, pain in the body and discharge through nose.

7. Mountain Sickness—Persons living in plains, when ascend mountains above 8000 ft. from sea level, develop symptoms of mountain sickness within 8-24 hours. The symptoms are breathlessness, headache, dizziness, nausea, vomiting, mental fatigue and even bluish tinge on skin, nails and lips. This is because partial pressure of oxygen PO_2 falls with the fall of atmospheric pressure and rise of altitude. This lowers

PO_2 in alveolar air and consequently reduces diffusion of oxygen into the blood. The fall of oxygenation of blood produces mountain sickness. For this reason persons living on mountains have more RBCs than those living in plains.

QUESTIONS

1. Describe organs of respiration in man.
2. What is pulmonary ventilation Discuss the mechanism in details with diagrams.
3. Differentiate between direct and indirect respiration and external and internal respiration.
4. Describe the mechanism of transport of gases.
5. Discuss role of haemoglobin in respiration.
6. What physiological mechanisms bring about an increase in rate and depth of breathing.
7. How is carbon dioxide carried by the blood from cells to lungs?
8. How carbon dioxide contents influence breathing?
9. Mention role of nasal passages.
10. How are turbinal bones arranged in nose and what is their importance?
11. What all activities occur during inspiration expiration?
12. What substance found in blood is the natural chemical stimulant for respiratory centre ?
13. Discuss the role of pneumotaxic centre in controlled breathing.
14. What are Hering-Breuer mechanism?
15. What will happen if an opening is made into the pleural cavity from the exterior ?
16. What is the difference between breathing and respiration?
17. Why does it becomes difficult to breath at high attitudes?
18. Why does breathing rate increase on high altitudes?
19. What are true vocal cords ? How these are formed?
20. What is Adam's apple?
21. What are the main respiratory muscles?
22. Define briefly
    (i) alveolus   (ii) pleursy   (iii) vital capacity of lungs   (iv) tidal volume   (v) dyspnea
    (vi) Asphyxia   (vii) Residual air   (viii) Chloride shift   (ix) Acidoses
23. Trace the path of air from nostrils to alveoli naming the parts in sequence and advantage of each.
24. Nasal passages are called filters and air conditioners. Why ?
25. What is Bohr's effect?
26. What are various factors for asphyxiation.
27. Why persons living on high altitudes have more RBCs than those living at sea level.
28. Give a graphic representation of mechanism of normal inspiration.
29. Give statistics of gaseous exchange between blood and atmospheric air.
30. What is oxygen carrying capacity of blood.
31. What do you understand by partial pressure of carbon dioxide ? What role it plays in breathing ?
32. What is epiglottis? What is its function?
33. Differentiate between
    (i) External and internal respiration. (ii) Anaerobic and aerobic respiration. (iii) Tracheoles and bronchioles.
    (iv) Inspired and expired air.   (v) Inspiratory reserve and expiratory reserve volume.
    (vi) Oxyhaemoglobin and Carbaminohaemoglobin.
34. Define the following terms:
    (i) Vital capacity   (ii) Residual volume   (iii) Bohr's effect
    (iv) Spiracle   (v) Inspiratory reserve volume.
35. Give average values of the following in normal adult human :
    (i) Vital capacity   (ii) Tidal volume   (iii) Residual volume
    (iv) Arterial pO_2;   (v) Venous pO_2 (vi) Alveolar pCO_2.
36. Describe how CO_2 concentration influences oxygen carrying capacity of blood?
37. Explain the following :
    (i) Oxygenation of blood promotes release of CO_2 from blood in lungs.
    (ii) Oxygen enters blood from alveolar air but CO_2 leaves blood to enter alveolar air.
    (iii) Gaseous exchange continues in lungs even during expiration.
    (iv) Atheletes have higher vital capacity.
    (v) Contraction of inspiratory muscles helps in inspiration, white their relaxation helps in expiration.
    (vi) More oxygen is released in active tissue than in a less active tissue.

CIRCULATION

CIRCULATORY SYSTEM

In multicellular organisms, the nutrients and oxygen are transported to various body cells and nitrogenous wastes and CO_2 are removed from these cells by an **extracellular fluid**. This flows throughout body practically contacting each body cell. The flow of this extracellular fluid through body is known as **circulation** and organs associated with its circulation form **circulatory system.**

FUNCTIONS OF CIRCULATORY SYSTEM

The functions of circulatory system in all living organisms are basically the same. These are

1.   **Transport of nutrients** from their site of absorption to every cell.
2.   **Transport of oxygen** from gills of lungs to all body cells and transport of CO_2 from cells to gills or lungs.
3.   **Transport of waste products of metabolism** from various body cells to excretory organs.
4.   **Transport of intermediate metabolites** from one organ to other for further and final metabolism, e.g. lactic acid produced in muscles during glucose metabolism is carried to liver for its final oxidation.
5.   **Transport of hormones** to target organs.
6.   Helps in **regulation of body temperature.**
7.   Helps in **maintaining homeostasis** by uniformly distributing water, H^+ ions and chemical substances.
8.   **Protection** against invasion or infection of micro-organisms.

A. Circulatory Mechanism in Unicellular Organisms

In unicellular organisms, the cells are in direct contact with the surrounding medium. The surface area : volume ratio is more. Thus, there is no need for a special circulatory system. **Diffusion, active** and **passive transport** and **cytoplasmic streaming** are sufficient to ensure adequate supply to every part of unicellular body.
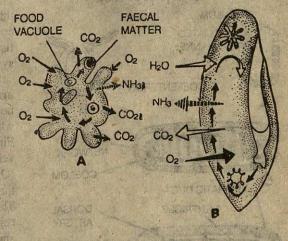
Fig. 19.1 Exchange of materials and streaming movement of cytoplasm in (A) Amoeba and (B) Paramecium.

B. Circulatory Mechanism in Multicellular Organisms

1. Invertebrates with no circulatory system—A circulatory system is absent in sponges, cnidarians, ctenophores, flatworms and nematodes. Because bodies of these animals are only a few cells thick and is bathed in water laden with oxygen and nutrients. Therefore, diffusion is an effective mechanism for distributing materials.

(a) **In sponges** the body wall is permeated by a system of canals bringing water in contact with body cells. The water circulating through spongocoel and canal system brings food and

oxygen to the cells.

(b) In **cnidarians**, the central gastro-vascular cavity serves both as a digestive and circulatory organ. The food organisms are digested in here and digested food diffuses into the cells lining gastro-vascular cavity and from there into the cells of outer layer.

(c) In **flatworms**, the branched intestine brings nutrients to all parts of body. The nutrients diffuse into the tissue fluid of mesenchyme, into the mesenchyme cells and then to the outer layer of body.

(d) In **roundworms**, the fluid present in the pseudocoel helps to circulate materials and to distribute them to all parts of body.
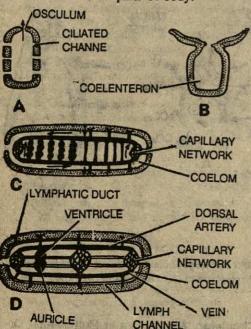
Fig. 19.2 **Transport of substances in invertebrates without circulatory system (a) Sponge (b) Hydra (c) Flatworm (d) Roundworm.**

C. Transport Mechanism in Complex Multicellular Animals

More complex multicellular organisms no longer remain in direct contact with the exterior and the rate of diffusion of substance is inadequate. The transport of substances in them is carried out with the help of **circulatory system**. It ranges from ciliated water – filled canals in jelly—fishes to the sophisticated **blood vascular system**. It consists of

1. A circulatory medium – **blood** and **lymph**
2. A system of blood vessels—**arteries, veins**

and **capillaries.**

3. A pumping organ—heart

Heart pumps blood to various parts of body through **arteries** and receives it back through **veins**. The blood collects digested food from intestinal wall and oxygen from lungs or gills on its way back to heart. The blood distributes them to body organs on being pumped to various parts of body.

OPEN AND CLOSED CIRCULATORY SYSTEM

A. Closed Circulatory System

In earthworm and all vertebrates the blood flows through closed vessels and nowhere in the body comes in direct contact with the body cells or tissues. This is known as **closed circulatory system.**

The blood from heart is pumped into the **arteries**. The arteries carry blood to the various body organs where these divide into **arterioles** which in turn ramify into very fine **capillaries**. Finally these capillaries join to form **veinules** and **veins**, that return blood to the heart. The materials (O_2 and food etc.) brought by the blood pass through the capillary walls into the **tissue fluid**. The nitrogenous wastes, CO_2 etc. from the tissue cells are collected in the blood inside the capillaries and are removed from there.

B. Open Circulatory System

In insects (Cockroach) and many molluscs the blood vessels do not divide into capillaries as in closed circulatory system. These open in wide spaces, the sinuses in the body cavity. The blood fills in the body cavity and bathes the body organs. The body cavity filled with blood is called **haemocoel** and blood as **haemolymph**. This type of circulatory system is called open circulatory system.

Blood flows at a very low velocity in the lacunae and sinuses. The oxygen carrying pigment is usually dissolved in plasma of blood.

The tissues are in direct contact with blood and exchange of respiratory gases, nutrients and waste products takes place directly between blood in the lacunae and sinuses and the surrounding tissues.
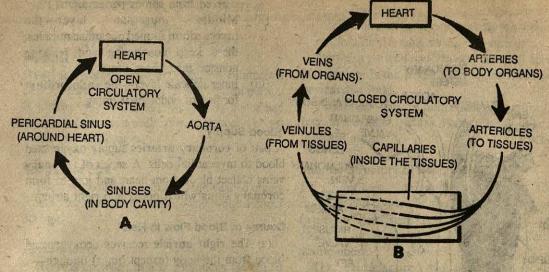
Fig. 19.3 A—Open type of circulatory system. B—Closed type of circulatory system.

A—In dorsal view

B—T.S. body of cockroach showing path of blood
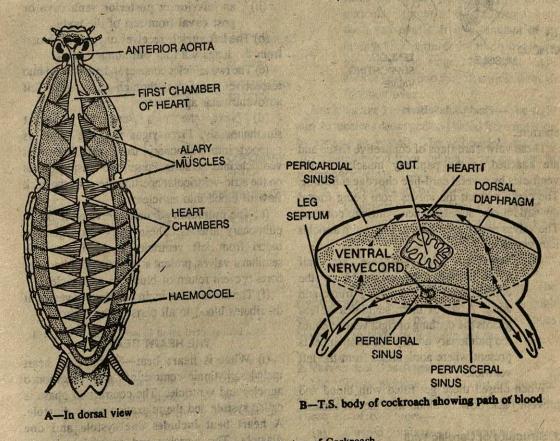
Fig. 19.4 Circulatory system of Cockroach.

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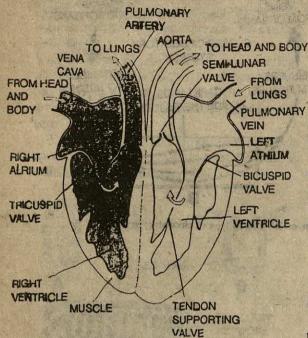
Fig. 19.6. L.S. Heart

aperture.

These valves are flaps of connective tissue and are attached to the papillary muscles of the ventricles by several card-like **chordae tendinae**. The cords prevent the valves from being forced upward into the auricles when ventricles contract. The valves permit the blood to flow from auricles into ventricles.

(b) **Semilunar valves**—These are half moon-shaped flaps arising from the endocardium of pulmonary trunk and aorta. A set of three semilunar valves guards the opening of right ventricle into the pulmonary aretery and another set is present where aorta arises from the left ventricle.

When closed these get filled with blood and prevent back flow of blood into the ventricles.

3. Structure of Cardiac Wall

The wall of heart in both auricles and ventricles is formed of following three layers—

(i) An outer thin layer—the **epicardium** derived from serous pericardium.

(ii) Middle muscular layer—the **myocardium** formed of cardiac muscles, these keep contracting and relaxing nonstop throughout life.

(iii) Inner delicate layer—the **endocardium** formed of endothelial lining.

Blood Supply

A pair of **coronary arteries** supply oxygenated blood to myocardial cells. A series of **coronary veins** collect blood from heart and join to form **coronary sinus** which opens into right atrium.

Course of Blood Flow in Heart

(a) The **right auricle** receives deoxygenated blood from the body (except lungs) through—

(i) a superior or anterior vena cava or precaval from head region and

(ii) an inferior or posterior vena cava or post caval from rest of the body.

(b) The **left auricle** receives oxygenated blood from the lungs via four **pulmonary veins**.

(c) The two auricles contract and push blood into respective ventricles through right and left atrioventricular apertures.

(d) Next, the two ventricles contract simultaneously. From right ventricle blood is pumped into pulmonary trunk and from left ventricle into the aorta. Presence of cuspid valves on the atrio-ventricular aperture prevents the back flow of blood into auricles.

(e) The **pulmonary trunk** is divided into two pulmonary arteries. These carry deoxygenated blood from left ventricle to the lungs. The semilunar valves, present at the base of pulmonary aorta prevent return of blood into ventricle.

(f) The **aorta** is the main distributing vessel. It distributes blood to all parts of the body.

THE HEART BEAT

(i) **What is heart beat**—Working of heart includes rhythmic contractions and relaxation o auricles and ventricles. The contraction phase is called **systole** and the relaxation phase **diastole**. **A heart beat includes one systole and one diastole.** The auricles and ventricles do not contract simultaneously. The heart beat is completed in following stages—

Stage 1. Simultaneous contraction of both the

VERTERBATE CIRCULATORY SYSTEM

HEART
(The pumping machine)

Position

Heart is situated almost in the middle of thoracic cavity between the lungs. Its lower conical portion is tilted to the left. It is protected by bones and muscles of the chest walls, ribs, back bones, breast bones and diaphragm.

Shape and Size

Heart is a hollow, muscular, cone-shaped organ. It is about the size of the fist and weighs about 300 gms.

Pericardium

Heart is enclosed in a membranous sac called **pericardium.** It is formed of following layers:
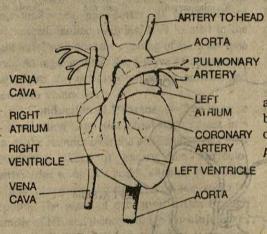
Fig. 19.5 External view of heart from ventral side.

1. **Fibrous pericardium**—It is the tough loosely fitted and inelastic sac around the heart. It is made up of tough white fibrous tissue.
2. **Serous pericardium**—It is smooth and moist and is formed of two thin layers.
   (a) **Parietal layer** forms lining of the fibrous pericardium.
   (b) **Visceral layer or epicardium** adheres to the heart forming its outer covering,

Between parietal and visceral layers of serous pericardium is the **pericardial space** filled with **pericardial fluid.**

Functions—Pericardium protects heart from injury, and against friction. Pericardial fluid keeps the heart moist.

Internal Structure of Heart

1. **Chambers**—Mammalian heart is four chambered. It consists of two **auricles or atria** and two **ventricles.** There is no **sinus venosus.** It gets absorbed in the wall of right atrium during development.

(1) *Auricles are* two upper thin walled chambers of the heart, separated by a thin **inter auricular septum.** Lying in the auricular septum is an oval depression, the **fossa ovalis.** It is a remnant of an embryonic aperture, **foramen ovale.** In the embryoric stage blood from right auricle passes into the left auricle through foramen ovale.

Auricles are receiving chambers—The right auricle receives deoxygenated blood from the body by two large vessels. The *left auricle* receives oxygenated blood from the lungs by two pairs of *pulmonary veins.*
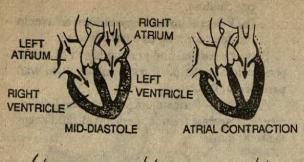
(2) Ventricles are two lower and thick walled chambers of heart. These are separated by a thick and obliquely placed **interventricular septum.** Therefore, the left ventricle is somewhat larger and its walls are thicker than the right ventricle.

Ventricles are distributing chambers. The **right ventricle** supplies blood to lung through **pulmonary aorta.** The **left ventricle** supplies blood to the body by a single **aorta.**

2. Valves and Openings

The various apertures in the heart are guarded by valves. These are derived from endocardium. These are of two types—

(a) **Cuspid valves**—A **tricuspid** valve guards the right atrio-ventricular aperture and a **bicuspid valve or mitral valve** is present on the left atrio-ventricular

Fig. 19.7 Rhythmic contraction of heart chambers and changes in pressure and volume

(Labels in figure: LEFT ATRIUM, RIGHT ATRIUM, LEFT VENTRICLE, RIGHT VENTRICLE, MID-DIASTOLE, ATRIAL CONTRACTION, ISOMETRIC VENTRICULAR CONTRACTION, VENTRICULAR EJECTION, ISOMETRIC VENTRICULAR RELAXATION)

uricles pushing the blood into ventricles which are in relaxing phase.

Stage 2. Stimultaneous contraction of ventricles forcing blood into the aorta and the pulmonary trunks. Along with it the auricles start relaxing.

Stage 3. In this stage both ventricles and auricles are relaxed or in diastole. This stage is called the **general pause** or **joint diastole.** During this stage blood enters the auricles from the great veins (superior and inferior vena cavae). At the end of this phase the next heart beat starts with the contraction of auricles.

The heart beats about 68-72 times a minute. This is called **heart rate.** At each heart beat ventricles pump about 70 ml blood. This volume is termed as **stroke volume.** It means heart pumps about 70 x 70 ml: 4900 ml. blood per minute. This is called **cardiac output** (C.O.). This can be calculated by—

C.O. =	H.R. x	S.V.
(Cardiac output)	Heart rate	(Stroke volume)
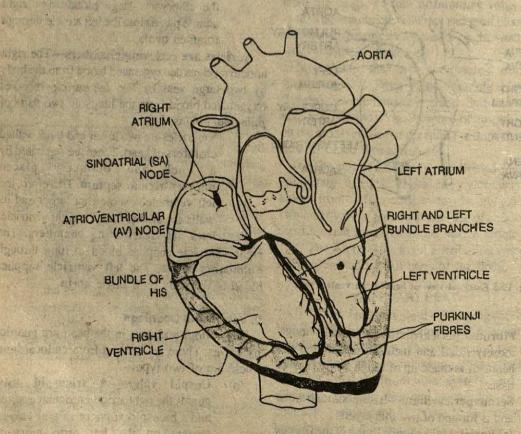
Fig. 19.8 Conducting System of Heart

(Labels in figure: AORTA, RIGHT ATRIUM, SINOATRIAL (SA) NODE, ATRIOVENTRICULAR (AV) NODE, BUNDLE OF HIS, RIGHT VENTRICLE, LEFT ATRIUM, RIGHT AND LEFT BUNDLE BRANCHES, LEFT VENTRICLE, PURKINJI FIBRES)

Regulation of Heartbeat

The normal rate of heartbeat is maintained by two regulating mechanisms—

1. Nervous Control—The **cardiac centre** lies in the medulla and is formed of **cardio-inhibitor** and **cardio-accelerator** parts. The former decreases the rate of heart beat and latter accelerates it. The cardio-inhibitor is connected with the heart through **vagus nerve** and cardio-accelerator through sympathetic nerve fibres.

2. Hormonal Control—**Adrenalin** and **thyroxin** influence heart rate independent of nervous system. A renalin increases heart beat by directly influencing S.A.—node. Thyroxin increases oxidative metabolism of body cells. This requires more oxygen and thus indirectly increases heart-rate.

(ii) Origin of Heartbeat—Mammalian heart is **myogenic** (*i.e.* wave of contraction originates in the specialized muscle fibres of heart). The **sino-atrial** or **sino-auricular node (SA node)** is the **pace-maker** or **pace-setter**. It is formed of specialized cardiac muscles. It is located in the right atrial wall near the opening of superior vena cava. At regular intervals, a wave of contraction starts here and is passed on to the auricles and thence to ventricles.

(iii) Conduction of Heartbeat— The impulse of contraction from sino-atrial node passes in a wave-like manner over the atria and causes their contraction. Then it excites the **auriculo-ventricular node** (AV node), situated in the right auricle along the lower part of interauricular septum. The wave of excitation passes through **bundle of His** and thence through **Purkinje fibres** into the walls of ventricles, causing the contraction of ventricular muscles.

The conduction of impulse of contraction through the conducting tissue is very fast.

THE HEART BLOCK

The conducting system of heart is made up of specialized muscle fibres. Any damage caused to these fibres either by mechanical injury or by degeneration due to some disease, impairs the path of impulse and interferes with the normal cardiac rhythm. This condition of altered **heartbeat** is called **heart block**. In such patients, a small transistorised pace-maker is fixed in the damaged part of the conducting system and is synchronized with the SA node. The heart resumes its coordinated cycle and can work normal for 1 1/2 to 2 years.

CARDIAC CYCLE

Cardiac cycle denotes the sequence of atrial and ventricular events which occur during each complete heart-beat. It is completed in about 0.8 seconds. It can be divided into following three phases:

Phase 1 The Arterial systole—It is simultaneous contraction of both the auricles. It lasts for about 0.15 seconds and pumps blood into the ventricles.

Phase 2 The ventricular systole—It is simultaneous contraction of both the ventricles. It lasts for about 0.3 seconds and pumps blood into the arteries.

Phase 3 The ventricular diastole—It is relaxation of ventricles and also of auricles. It is called **general pause** and is of about 0.5 seconds. During general pause blood from vena cavae is poured into the auricles.

HEART SOUNDS

Each heart beat is accompanied by two heart sounds. With a stethoscope, these sounds are heard as **lub** and **dup**.

(i)   The **lubb** (= first sound) **sound** is lower and lasts longer. It is produced by the contraction of ventricular muscles and the vibrations set up by the **closure**. It is also called **systolic sound** of **tricuspid** and **bicuspid** (= mitral) **valves**.

(ii) The **dup sound** (= second heart sound) is caused by the **closure of semilunar valves** of the aorta and pulmonary trunk. It is **diastolic sound**. It is short and sharp.

(iii) **Heart murmur** is the abnormal sound produced either by incomplete closing of valves (valvular insufficiency) or by their narrowing (stenosis).

PULSE RATE

The beating of the heart is also felt in the arteries as regular jerks, called **pulse**. Each **venticular** systole starts a new pulse. It proceeds as a wave of expansion throughout the arteries disappearing in the capillaries. The pulse rate is same as the heart rate.

Pulse can be felth wherever an artery lies near the surface, such as radial artery at the wrist; temporal artery in front of ear; common cartid artery in the neck, facialartery on the corners of mouth, the brachial artery at the bend of elbow and in the leg near ankle bone.

BLOOD PRESSURE (B.P.)

The force of blood against the walls of blood vessels is known as blood pressure. The pressure of blood in the circulatory system depends upon:

1. Changes of the circulatory space due to contraction and relaxation of heart and blood vessels.

2. Amount of blood entering and leaving a blood vessel.

3. Total blood volume.

4. Viscosity of blood.

5. Elasticity of blood vessels.

Systolic pressure (S.P.) is the pressure of blood during systolic phase. It is maximum and is responsible for movement of blood in the arteries. Diastolic pressure (D.P.) is the blood pressure during diastolic phase of heart, when blood is received in the heart.

Normal Systolic pressure is—125-130 Hg mm.

Normal Diastolic pressure is—70-90 Hg mm.

In medical terms B.P. is represented by 120/80. In high blood pressure (hypertension), the systolic pressure is above 150 Hg mm and diastolic pressure above 100 Hg mm. In low blood pressure (hypotension) systolic pressure is less than 100 Hg mm and diastolic below 50 Hg mm. High BP 220/120 may burst blood vessels of brain.

High B.P. is usually associated with

(i)   hardening of arteries in old age (arteriosclerosis).

(ii)   severe kidney disease.

(iii)   strain or emotional stress.

The blood pressure is measured by sphygmomanometer.

THE ELECTROCARDIOGRAM (E.C.G.)

Impulse conduction generates tiny electrical currents in the heart, that spread through surrounding tissues to the surface of body. If electrodes are properly placed on the body surface at specific places, the electric potentials generated by the heart during the transmission of impulse from SA node through conducting system can be recorded. Such a record is called electrocardiogram (ECG).

A normal ECG is composed of a P wave, a QRS complex and a T wave, where

P = depolarization of atrium.

QRS = depolarization of ventricle.

T = repolarization of ventricle.
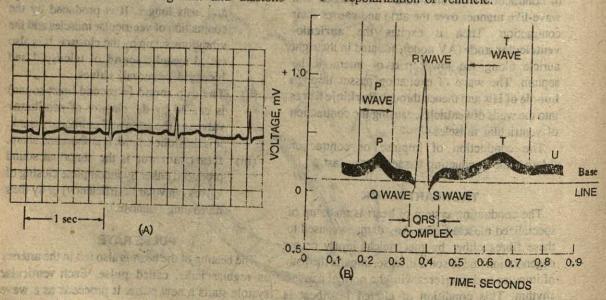
Fig. 19.9 (A) Normal ECG deflection. depolarization and repolarization. (B) Compnent of E.C.G.

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Some Heart Diseases

ECG is used in the detection of various heart diseases. Some of these heart diseases are as follows:

1. **Heart block (one: two heart block)**—In the condition there are two arterial beats for each ventricular contraction.

2. **Ventricular fibrillation**—Different regions of ventricle contract at random.

3. **Valvular defects**—One or more heart valves may become constricted or do not close the opening completely.

4. **Angina pectoris**—Due to inadequate blood supply to the heart muscles as a result of arteriosclerosis severe pain occurs in the breast region.

5. **Coronary thrombosis**—Blockage of coronary artery due to the presence of a small clot or thrombus. This also leads to insufficient or no supply of blood to heart muscle.

6. **Myocardial damage**—Insufficient supply of blood to heart muscles causes damage and results in heart attack.

7. **Rheumatic heart**—Due to bacterial infection of *Streptococcus viridans*, the heart valves especially the tricuspid valve does not operate properly. The cardiac muscles get weakened and heart gets enlarged.

BLOOD VESSELS
(Arteries, Veins and Capillaries)
Arteries

(i) Arteries carry blood away from heart.(ii) All arteries except pulmonary artery carry oxygenated blood. (Pulmonary artery carries deoxygenated blood from right ventricle to lung) (iii) Arteries
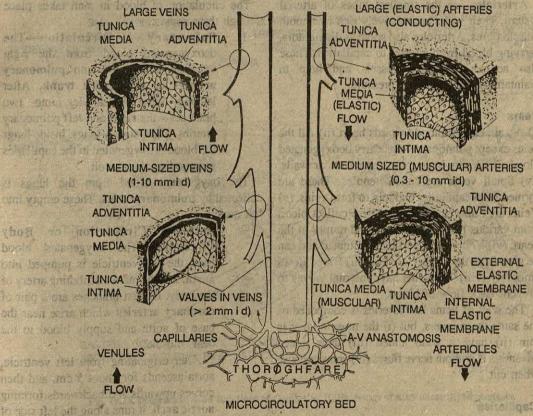
Fig. 19.10 Diagram to show differences and interrelationship between artery and vein

have thick, elastic and muscular walls. (iv) Arteries branch into small arteries, arterioles and end in capillaries. (v) Arteries are distributing vessels. These carry blood from heart to various body organs. (vi) Arteries are deeply situated. (vii) These carry blood under pressure and blood flows with jerks. (viii) Their lumen is without valves.

Structure of Artery—The wall of an artery consists of following three coats or tunics:

1. Tunica adventitia. It is the outermost layer. It is made up of white fibrous connective tissue that carries small vessels and nerves to nourish the arterial wall.

2. Tunica media—It is the middle thick coat. It is formed of smooth muscle fibres and connective tissue.

3. Tunica intima—It is the inner thin and delicate lining of endothelial cells.

Arterioles are the smallest tubes of arterial system. Their walls are relatively rich in smooth muscle fibres. Arterioles also serve as distributors, carrying blood from arteries to capillaries. These also act as resistance vessels and help in maintaining normal blood pressure.

Veins

(i) A vein carries blood towards heart. (ii) All the veins except pulmonary veins carry deoxygenated blood. (iii) Veins have thin, less muscular walls. (iv) Small veins are called venules. These are formed from capillaries and join to form veins. (v) Veins are collecting vessels. These collect blood from various parts of the body and empty in the heart. (vi) Veins are superficially situated and can be seen from the surface of skin (vii) Blood flows smoothly (viii) The veins have internal valves to prevent back flow of blood.

The wall of veins like arteries is composed of the same three layers, but (i) the muscle layer is thin (ii) have a wide lumen (iii) their tunica adventitia is without nerve fibres (iv) veins collapse when cut.

Capillaries

Capillaries are microscopic vessels that carry blood from arterioles to small veins or venules. The wall of capillaries is formed of a single layer of endothelial cells. These lie in contact with the body
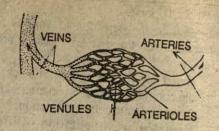
Fig. 19.11 Diagram showing interrelationship between artery, vein and capillary

tissues. These supply food and oxygen to the tissue cells and remove injurious wastes. The leucocytes squeeze out through the capillary walls into the surrounding tissue to attack the invading bacteria. The phenomenon of squeezing out of leucocytes is called **diapedasis**.

CIRCULATION OF BLOOD

The circulation of blood in man takes place through three routes:

1. **Pulmonary circulation**—The deoxygenated blood from the right ventricle is pumped into **pulmonary arteries** or **pulmonary trunk**. After leaving heart it divides into two branches—the **right** and **left** pulmonary arteries. These supply lungs. Inside lungs the blood is oxygenated in the capillaries surrounding the alveoli.

The oxygenated blood from the lungs is collected by **pulmonary veins**. These empty into left auricle.

2. **Systemic Circulation or Body Circulation**—The oxygenated blood from the left ventricle is pumped into **aorta**. It is the main distributing artery of the body. Its first branches are a pair of **coronary arteries** which arise near the base of aorta and supply blood to the heart muscles.

After originating from left ventricle, aorta ascends for about 5 cm. and then curves upwards and backwards forming **aortic arch**. It runs along the left side of vertebral column through thoracic and abdominal cavities and goes down. It is called **dorsal aorta**. From the upper part of the curve of aorta arise following three

arteries—

1. **Innominate (brachiocephalic) artery**

   (i) **Right common carotid**—to head and sense organs

   (ii) **Right subclavian**—to vertebral column and right arm.

2. **Left subclavian**—to vertebral column and left arm.

3. **Left common carotid**—to left half of head. **Descending thoracic aorta** gives visceral branches to pericardium, **brouchu**, oesophagus, diaphragm and chest muscles

   Descending abdominal aorta gives arteries to—

   (i) **Coeliac artery** to stomach, liver and spleen.

   (ii) **Suprarenal artery** to suprarenal glands.

   (iii) **Superior mesenteric artery** to small intestine.

   (iv) **Spermatic artery** or **ovarian artery** to gonads.

   (v) **Inferior mesenteric artery** to large intestine.

   (vi) **Renal arteries** to kidneys.

   After this abdominal aorta bifurcates into two **iliac arteries** that supply blood to leg muscles.

   Corresponding veins collect blood from these organs and empty into superior and inferior vena cavae which open into right auricle.

3. **Hepatic Portal Circulation**—The veins from various parts of alimentary canal (**mesenteric veins**), spleen (**splenic vein**) and pancreas (**pancreatic vein**) join to form **hepatic portal vein**. It carries blood with digested food products (glucose, amino acids, glycerols and fatty acids)
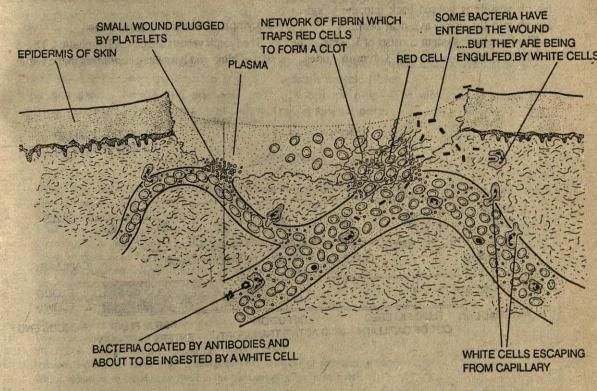
Fig. 19.13. Diagram to show functions of capillaries. (i) Exchange of substances (ii) Diapedesis.

Labels in figure:
- SMALL WOUND PLUGGED BY PLATELETS
- EPIDERMIS OF SKIN
- PLASMA
- NETWORK OF FIBRIN WHICH TRAPS RED CELLS TO FORM A CLOT
- RED CELL
- SOME BACTERIA HAVE ENTERED THE WOUND ....BUT THEY ARE BEING ENGULFED BY WHITE CELLS
- BACTERIA COATED BY ANTIBODIES AND ABOUT TO BE INGESTED BY A WHITE CELL
- WHITE CELLS ESCAPING FROM CAPILLARY

to liver, where it ramifies into capillaries and supplies blood to hepatic cells. These capillaries then rejoin to form a pair of **hepatic veins.** These open in the upper part of inferior vena cava and finally into right ventricle. In doing so, the digested food collected by blood from intestine is received by hepatic cells for storage and metabolism.

LYMPHATIC SYSTEM

When blood flows from the arterial end to its venous end, its fluid plasma filters out of the thin-walled capillaries at the arterial end, due to pressure difference. This fluid is called **interstitial fluid** or **tissue fluid.** It carries salts, sugars, amino-acids and gases dissolved in it. A part of the tissue fluid gets back (reabsorbed) into the capillaries at their venous ends to complete the blood volume. Most of this fluid flows through a system of fine thin-walled channels that form **lymphatic system.** The fluid collected by the lymph vessels is poured back into the blood as lymph into the vena cava near heart.

The **lymphatic system** consists of 1. lymph (the fluid); 2. lymph vessels and 3. lymph nodes.

1. Lymph

Lymph is described as filtered blood plasma, but it has lower protein contents than plasma. It is clear, watery fluid, flowing through lymphatic vessels. It is a link between blood and tissue fluid. It contains (i) fluid **plasma** with low protein content and (ii) **lymphocytes** that walk out of capillary walls.

Functions of lymph—(i) It helps in the distribution of nutrients and oxygen to tissue cells.

(ii) It helps in the removal of nitrogenous wastes and **carbondioxide** from the tissue cells and pass them to the blood.

(iii) It absorbs fatty acids and glycerols (digested fat) in the villi of intestine through *lacteals*

(iv) Its *lymphocytes* destroy harmful pathogens.

(v) It controls concentration of proteins in the tissue fluid.

(vi) It serves to equalize body temperature.

2. Lymph Vessels of Lymphatics

The lymph vessels are called lymphatics. These start as blind end lymphatic *capillares* in the tissue
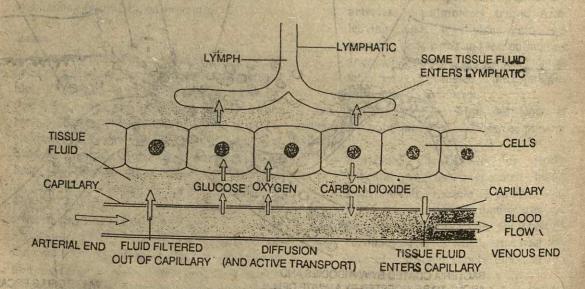
Fig. 19.14 Relation between blood, lymph and tissue fluid.

spaces and join to form larger ducts. The lymphatic capillaries arising in the intestinal villi are called **lacteals.** These absorb digested fat from the intestine as **chilomicrones.** After a fatty meal their lymph appears milky and is called **chyle.** Lymphatics form a net in the body and have valves to maintain flow of lymph towards large veins. These return water and proteins to the blood.

3. Lymph Nodes

At specific points, there are enlargements in the lymph vessels, like beads in a string. These are called **lymph nodes.** In lymph nodes the lymphatic tissue is separated into compartments by fibrous partitions. The different lymphatics enter the lymph nodes and break up into fine branches which join to form efferent lymphatics (like portal system).

Functions: (i) Lymph nodes filter out cell debris and other injurious substances.

(ii) produce lymphocytes and monocytes.

(iii) phagocytise and destroy bacteria and other pathogens.

(iv) synthesize certain antibodies.

Location—Lymph nodes are abundant in neck, arm-pit and groin. **Tonsils** and **adenoids** are masses of lymphatic tissue. **Thymus and spleen** are important lymphatic organs of body.

Significance of Lymphatic System

1. Lymphatic system primarily serves as an auxilliary system for the return of fluid from tissue fluid to blood. If there is no lymphatic return, blood volume would continue to reduce and tissue fluid increases because of leakage at capillary level.

2. It returns proteins to blood and helps in maintaining osmotic concentration of blood to facilitate exchange of materials between blood and tissue cells.

SPLEEN

Spleen is the largest lymphatic organ in human body. It is an irregular somewhat flattened and elongated body of dark red colour. It is located along the posterior margin of stomach.

Histological Structure

1. **Serous membrane**—It forms the outer covering of the spleen formed of peritoneum.

2. **Capsule**—It invests the splenic pulp. It is formed of elastic **fibrous connective tissue and smooth muscle fibres.**

3. **Splenic pulp**—The substance of spleen is called **splenic pulp.**

QUESTIONS

1. Name the process in which water molecules move from the region of their higher concentration to the region of their lower concentration in plants.

2. What is the function of root hairs?

3. What is the accepted theory of ascent of sap?

4. Which tissue is responsible for the conduction of water and minerals from root to leaves?

5. Name the plant tissue that helps in translocation of food prepared by leaves.

6. Name the substances that are transported through xylem and phloem.

7. Write two functions of stomata.

8. Write about the utility of xylem for the plants.

9. Name two plants which show guttation.

10. What conditions lead to guttation in plants?

11. When can guttation be seen?

12. What is the number of R.B.Cs in one ml. of man's blood?

13. Describe the role of valves at the openings between auricles and ventricles in human heart.

14. Which substance of blood is involved in the transport of gases in animals?

15. Fill in the blanks

(i) Lymph is _____ blood.

(ii) Blood is a _____ connective tissue.

(iii) _____ is the most efficient oxygen carrier.

(iv) _____ is responsible for absorption of water and minerals.

(v) Valves are present in _____ to direct blood flow in them towards heart.

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(vi)   Streaming movement of cytoplasm is called_____.

(vii)   Haemolymph of cockroach performs all the functions of blood except for the transport of_____.

16.   What is the function of blood platets ?

17.   Which artery carries deoxygenated blood ?

18.   Name the vein which starts in capillmies and ends in capillaries.

19.   Give reasons

    (i)   Why a transport system is not required in simple animals ?

    (ii)   Why blood of cockroach does not help in transport of oxygen ?

    (iii)   Heart of cockroach is thin-walked. How does it pump blood ?

20.   Differentiate between the following

    (i)   Blood and lymph.

    (ii)   Systemic and pulmonary circulation.

    (iii)   Artery and vein.

    (iv)   Open circulation and closed circulation.

    (v)   Blood of earthworm and man.

    (vi)   Cyclosis and plasmolysis.

    (vii)   Body cavity and haemocoel.

    (viii)   R.B.C. and W.B.C.

21.   Distinguish between functions of RBCs and WBCs.

22.   Describe significance of transpiration.

23.   Define the following terms—

Cyclosis, osmosis diffusion, haemolymph.

24.   Give the functions of lymph.

25.   There is no haemoglobin in the blood of cockroach. How does it transport oxygen to the various tissues ?

26.   Trace the relation betwen artery, vein and capillary.

27.   What is double circulation? In which animals is it found?

28.   How are turgor movements caused?

29.   Describe the functions of plasma.

30.   Write two important functions of blood.

31.   What is the significance of hepatic portal system in man ?

32.   Why water is so important for plants?

33.   Explain the mechanism of opening and closing of stomata.

34.   Describe the functions of blood.

35.   Write an essay on internal transport in man.

36.   Define translocation. Name the tissues through which water and prepared food are conducted. Describe an experiment to prove conduction of water through named tissue.

37.   What are various components of human blood? Give their names and functions.

38.   · How will you demonstrate that water rises through xylem in plants?

39.   By means of labelled diagram alone, trace the path of water from soil to the xylei vessels of plants.

40.   With the help of labelled illustration alone, give a schematic representation of the circulatory system in man.

41.   Select the most appopriate answer or answers from Column B for the description Column A.

Column A		Column B
(i) No Circulatory system	a.	Insect
(ii) Open circulatory system	b.	Bird
(iii) Closed circulatory system	c.	Flatworm
(iv) Heart with two atria and two ventricles	d.	Earthworm

42.   Fill in the blanks:

    (i)   Haemoglobin is a pigment that transports _____.

    (ii)   When the proteins involved in blood clotting are removed from plasma, the remaining fluid is called

    _____.

    (iii)   The _____ fraction of plasma proteins contains many types of anti-bodies.

    (iv)   A deficiency in haemoglobin is referred to as_____.

43.   Select the most appropriate term in Column B to fit the description in Column A.

Column A		Column B
(i) Transport oxygen	a.	Platelets
(ii) Principal phagocytic cells in blood	b.	Red blood cells
(iii) Release histamine	c.	Macrophages
(iv) Develop from monocytes	d.	Basophils
(v) Initiate clotting	e.	Neutrophils

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f. Thrombin

(vi) Prothrombin requires vitamin_____for its production.

(vii) In the presence of thrombin, fibrinogen is converted to the insoluble protein_____.

44. Fill in the blanks:

(i) _____are blood vessels important in maintaining appropriate blood pressure.

(ii) The vessels through which nutrients and other materials were exchanged are_____.

(iii) In birds and mammals blood leaving the right ventricle enters one of the_____:

(iv) The_____valves guard the exists of the heart.

(v) The portion of the cardiac cycle during which the heart contracts is referred to as_____; the relaxation phase is_____.

(vi) The cardiac output is the_____.

(vii) According to Starling's law of the heart, the greater the amount of blood delivered to the heart by the veins,_____.

(viii) The force exerted by the blood against the inner walls of the blood vessels is known as_____.

(ix) Blood pressure is determined by_____ and by _____.

(x) The largest artery in the human body is the_____.

(xi) The carotid arteries deliver blood to the _____.

(xii) The renal veins deliver blood from the_____; the hepatic veins deliver blood from the_____.

(xiii) The term myocardial infarction (MI) is used as a synonym for_____.

(xiv) Baroreceptors are sensitive to changes in_____ _____.

(xv) The angiotensins are a group of hormones that are powerful_____.

Excretion is the process by which living organisms get rid of their metabolic waste products. These if retained in the body are toxic. The organs associated with the process of excretion are called **excretory organs**. The unwanted substances that are excreted out of the body are **excretory products** or **waste products**. Excretory organs also help in maintaining the proper concentration of inorganic ions (Osmotic balance) and right amount of water (Osmoregulation) in the body.
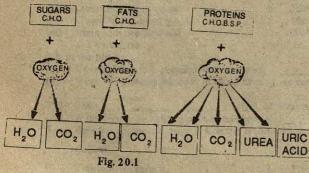
Nature of Excretory Products

Living cells are engaged in various synthetic (anabolic) and oxidative (catabolic) activities in both plants and animals. The chief metabolic by-products of these metabolic processes in animals may be grouped under the following two heads—

1. Respiratory Waste Products

2. Nitrogenous Waste Products

1. Respiratory Waste Products

The catabolic waste products of various types of foodstuffs are CO_2 and water. In lower animals CO_2 is eliminated directly into the environment through the general body surface. In higher animals it is excreted with the expired air through the lungs. Excess of water is eliminated in the form of urine and sweat.

Fig. 20.1

2. Nitrogenous Waste Products

The nitrogenous waste products are derived from the deamination of the excess of amino acids taken in with the diet and also from the breakdown of animals proteins and nucleic acids. Following

are the specific nitrogenous waste products excreted by the animals :

1. Ammonia. It is formed by the deamination of amino acids during protein metabolism. Ammonia is highly toxic and its rapid elimination is essential. It is highly soluble in water and is quickly eliminated in surrounding water (aquatic animals such as Protozoa, *Hydra,* etc.).

2. Urea. It is less toxic than ammonia. Most mammals, fishes and amphibians excrete their nitrogenous waste products in the form of urea.

3. Uric acid. Insects, some snails, birds and reptiles with few exceptions, excrete uric acid. Uric acid is excreted in solid form. As uric acid is insoluble in water, it crystallizes out from the fluid urine and water is reabsorbed, thereby allowing conservation of water.

4. Amino acid. In certain animals like molluses and echinoderms, the excess of amino acids is removed as such without undergoing any change.

5. Other nitrogenous compounds. Allantoin and allantoic acid are other nitrogenous excretory products. These are insoluble in water and are used during embryonic development by amniotes with shelled eggs.

There are certain other nitrogenous waste products such as guanine and adenine from nucleic acid break down and creatine from the creatine of muscles that are excreted along with other nitrogenous waste products in the urine.

3. Mineral Ions

Sodium, potassium, calcium, magnesium, chloride and ammonia are the essential mineral ions of the animals. The excess of these ions taken in with the diets are excreted by one means or the other.

Excretion of Nitrogenous Wastes

Nitrogenous waste products are eliminated in three principal forms : *ammonia, urea* and *uric acid*. The compound that is actually excreted is correlated with the habitat and life style of the

living beings.

1. Ammonotelism

Excretion of ammonia to eliminate extra nitrogen from body is called **ammonotelism** and animal excreting ammonia as their nitrogenous wastes are referred to as **ammonotelic.**

Ammonia is the basic metabolic catabolic of proteins. It is highly soluble in water and is highly toxic. In marine invertebrates its concentration in body fluids ranges from 0.4 mg to 4.8 mg per 100 mĺ. If its concentration exceeds 5 mg. per 100 ml. in rabbit, the rabbit dies off. For this reason ammonia shall be eliminated from blood as rapidly as possible. Moreover, a large amount of water is required for dissolving ammonia and for its elimination. Only simple aquatic animals can afford to excrete ammonia because it can diffuse out into the surrounding water as soon as it is formed.

Ammonia is excreted in aquatic invertebrates such as protozoans, sponges, jelly fishes and fresh water fishes. Polychaete worms, cephalopods and other molluscs and crustaceans are also ammotelic.

2. Ureotelism

Elimination of nitrogenous waste mainly as *urea* is called **ureotelism.** Animals excreting urea are **ureotelic organisms.**

Ureotelism is found in terrestrial, and semiterrestrial animals : Amphibians like frogs and toads, mammals, cartilaginous fishes (elasmobranch fishes) and semiaquatic and aquatic reptiles, terrapins, turtles etc.

Terrestrial animals have shortage of water. Therefore, excretion of ammonia is out of question, because higher concentration of ammonia is deadly poisonous and they do not have plenty of water for its dilution. In the liver of such animals from NH_3 and CO_2 urea is synthesized.

Urea is also poisonous in higher concentration but far less poisonous than ammonia and animal can afford to excrete it at a slower rate. A large amount of water is required for getting rid of urea from blood stream, and they excrete sufficient volume of water. Marine fishes excrete urea and not ammonia. These are known as *ureotelic.*They cannot afford to excrete ammonia because of several reasons. In **marine cartilaginous fishes** (elasmobranchs) the body fluids are to be maintained hypertonic to the sea water. This is brought about by retaining urea in their blood.

These retain 2 to 2.5 per cent of urea in the blood and thus maintain themselves hyperosmotic to their medium.

3. Uricotelism

Excretion of *uric acid* so as to eliminate nitrogenous wastes is termed as **uricotelism** and such animals are called **uricotelic.** Uricotelism is found in all birds, insects, some reptiles.

Uric acid is least toxic of the three nitrogenous wastes and least soluble in water. It crystalizes out of the solution and is excreted out as a solid waste. In uricotelic forms uric acid is synthesized from ammonia in the liver.

The uric acid is excreted as solid or semi-solid and is seen in all those animals which live on dry land and specially in desert. The embryos developing from cleidoic eggs (of gastropods, reptiles and birds) also excrete uric acid only, because it can be retained in the body without causing any harm. **Phrynosma,** a spiny lizard, excretes balls of uric acid. Birds excrete uric acid in semi-solid form.

1. Kidneys

   (i)   Nitrogenous wastes (from catabolism of protein and nucleic acid)
   (ii) Excess of water and minerals
   (iii) Toxins

2. Liver

   (i)   Conversion of ammonia to urea

3. Skin

   (i)   Water. (ii) Mineral salts
   (iii) Small amount of nitrogenous wastes
   (iv) Sweat glands

4. Lungs

   (i)   Carbon dioxide (ii) Water by evaporation
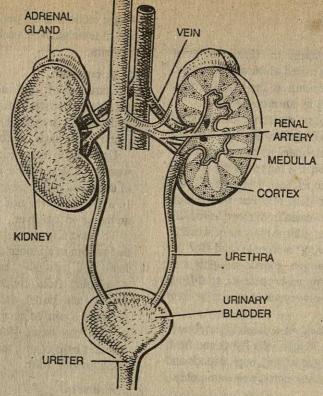
5. Intestine

   (i)   Undigested food residue.
   (ii) Some metabolic wastes (bile salts, bile pigments)

URINARY SYSTEM

Urinary system is associated with removal of nitrogenous waste products and maintenance of osmotic balance. It consists of

1. A pair of kidneys
2. A pair of ureters
3. Urinary bladder and
4. Urethra

Fig. 20.2 Urinary organs of man

KIDNEY

Position—Kidneys are located in the abdominal cavity, one on either side of vertebral column just beneath the diaphragm. These are attached to the dorsal abdominal wall by peritoneum, called **mesorchium**. Left kidney is placed slightly higher than the right one.

External structure—kidneys are chocolate brown, bean-shaped structures. Each kidney is about 11.25cm. long, 5-7.5 cm. broad and 2.5 cm thick. The outer margin is convex. The inner concave margin presents a notch, called *hilum*. Ureter and renal vein comes out of the kidney and renal artery enters in through **hilum**. Kidney is enclosed in a tough *renal capsule*, formed of white fibrous tissue.

Internal Structure of Kidney

A longitudinal section of kidney shows two distinct regions—

(i) Outer dark red layer—**renal cortex**, contains Malpighian corpuscle and both convoluted tubules.

(ii) Inner, pale zone-the **medulla**, contains Henle's loop and collecting tubules.

FIG. 276 Section through kidney

Fig. 20.3 V.S. Kidney

ARTERIOLE FROM RENAL ARTERY

VENULE TO RENAL VEIN

MALPIGHIAN CAPSULE

GLOMERULUS OF CAPSULE

TUBULE

U-SHAPED LOOP OF TUBULE

NETWORK OF CAPILLARIES AROUND TUBULE
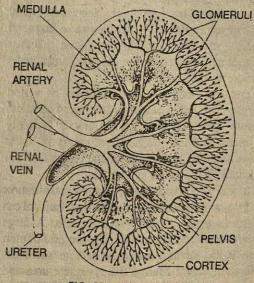
URINE-COLLECTING TUBULE OPENS IN PELVIS OF KIDNEY
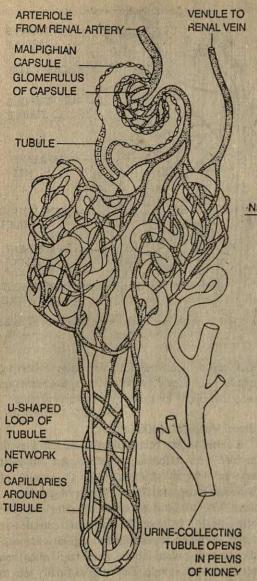
Fig. 20.4 Structure of a nephron.

Microscopic Structure Each human kidney is formed of about 1.25 **million uriniferous tubules** called **nephrons.** These are held together in the connective tissue. The nephrons are structural as well as functional units of kidney. Each nephron is along coiled tube. It can be divided into following parts

NEPHRON
- 1. RENAL CORPUSCLE — BOWMAN'S CAPSULE / GLOMERULUS
- 2. NEPHRIC TUBULE — PROXIMAL CONVOLUTED TUBULE / HENLE'S LOOP / DESTAL CONVOLUTED TUBULE
- 3. COLLECTING TUBULE

Fig. 20.5 Summary of various parts of a nephron

1. Malpighian Corpuscle or Renal Corpuscle. The malpighian corpuscle is formed of two parts—(i) **Bowman's capsule.** The blind end of nephron is like a double walled cup. It is called Bowman's capsule. Its outer layer is formed of plattered epithelial cells and inner layer of specialized **podocyte cells.** (ii) **Golomerulus.** The cavity of the cup encloses a bunch of capillaries, the glomerulus. It is formed from the capillaries of **afferent and efferent arterioles.** The afferent **arteriole** brings blood into the glomerulus and **efferent arteriole** collects blood from here. The Bowman's capsule along with its glomerulus is called **Malpighian corpuscle.** It lies in the cortex part of kidney.

2. Secretory part of Uriniferous tubule. The remaining part of nephron after the Bowman's capsule is called secretory part. It is lined with ciliated epithelium. It is differentiated into following four parts—

(i) Proximal convoluted tubule. It lies next to the Bowman's capsule. It is a wide tube lined with a layer of columnar epithelial cells having brush border.

(ii) Loop of Henle. Henle's loop is U-shaped. It lies in the medulla and is formed of a **descending limb** and an *ascending limb.*

Medulla is formed of about a dozen or so triangular masses, called **renal pyramids.** The **base** or wide margin of each pyramid faces towards cortex and its narrow **apex** or papilla opens in the calyx part of renal pelvis The pyramids have a striated appearance. The **cortex** between two adjacent pyramids forms the so called renal columns
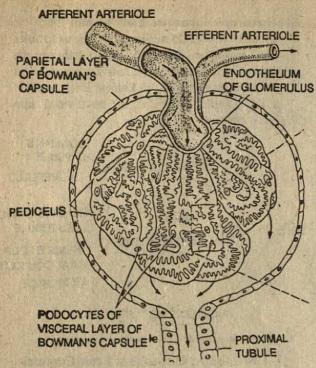
Fig. 20.6 Structure of Malpighian capsule

Fig. 20.8′ A single renal tube or nephron with its blood supply.

(iii) Distal convoluted tubule. It lies near glomerulus, and opens into a straight collecting tubule.

3. Collecting tubule. A collecting tubule receives distal tubules of several nephrons. These

Fig. 20.7 Electron micrographic diagram to show podocyte of Bowman's epithelium and its relatino with the endothelium orf glomerular capillary.

join larger tubules and all the large collecting tubules of one renal pyramid converge to form one tube that opens into one of the small calyces.

Blood Vessels of Kidneys

A **renal artery** brings blood to each kidney. It divides into afferent arterioles. An **afferent arteriole** forms glomerulus in the cavity of Bowman's capsule. The capillaries of glomerulus them join to form an **efferent arteriole.** The efferent arteriole leaves the Bowman's capsule and forms a network of **peritubular capillaries** around the remaining renal tubule. These capillaries then rejoin to form venule. The venules finally join to form the renal vein which drains blood from kidney.

Functions of Kidney

Kidneys perform two main functions 1. Formation of urine 2. Homeostasis

1. Formation of Urine—The formation of urine involves three main process :-(i) **Ultrafiltration,** (ii) **selective reabsorption** and

(iii) **Secretion.**

Renal Artery→Afferent arteriole→Glomerulus

Peritubular

Renal vein←Venule←Capillary net ← efferent arteriole

(i) Ultrafiltration or Glomerular filtration
Bowman's capsules act as ultra-filters. As blood flows through glomerular capillaries, water and all the substances of plasma except blood cells and plasma protein filter out of the blood into Bowmans capsules. Filtration occurs rapidly because of the following reasons (i) Blood is separated from the cavity of Bowman's capsule by two very thin membranes **The endothelial layer of blood capillaries and epithelial layer of Bowman's capsule**

(ii) The capillary wall has numerous fine pores of about 0.1 mm diameter.

(iii) The epithelial cells of Bowman's capsule are specialized and are called podocytes. The fine or minor processes or podocytes reach upto the basement membrane of glomerular capillaries, establishing a very close contact.

(iv) Afferent arteriole is wider than the efferent arteriole. Therefore, the amount of blood that enters the efferents arteriole in a definite time is not fully drained out by efferent arteriote. This increases the **hydrostatic pressure in the capillary** network of glomerulus. The effective filtration pressure (EFP) or pressure gradient responsible for it filtration is the outcome of the interaction of following pressures.

(i) The glomerular hydrostatic pressure or the capillary pressure is the main driving force that tends to move fluid out of the glomeruli. It is exerted by blood while passing through glomerulus. It is +75 mm. Hg.

(ii) The capsular hydrostatic pressure (renal interstitial pressure + renal intratubular pressure) about 20 mm Hg and blood colloidal osmotic pressure about 30 mm Hg exert force against capillary pressure.
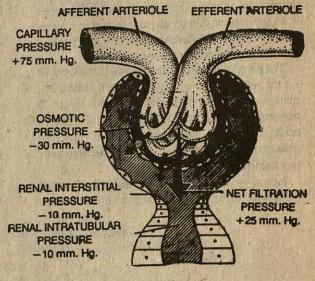
Fig. 20.9. Diagrammatic representation of ultrafiltration is about (+ 72—20—30) = + 25 mm Hg.

Therefore, the **net filtration pressure** responsible for filtration is about (+75—20—30) = +25 mm Hg.

This filtration is called **ultrafiltration.** As a result of ultrafiltration almost all the substances dissolved in plasma (urea, salts, glucose, creatine etc.) along with water except blood cells and colloids and certain plasma proteins filter out into the cavity of Bowman's capsule. The filtrate is similar to plasma and is called **nephric filtrate or glomerular filterate.** Golemerular filtration rate in a normal adult is about 120 ml per min. The

average volume filtered from the plasma into Bowman's capsule is about 190 litres per day.

2. Tubular reabsorption

Since the function of nephron is exclusively of a filter, not only urea but even the useful substances like glucose, amino acid, inorganic salts, PO_4 ions and vitamin C, etc. also diffuse out into the nephric filtrate. Their removal from the plasma along with urea will be harmful to the body. Therefore, the useful substances and a major portion of water are reabsorbed from the filtrate into the blood. For this purpose, the efferent arterioles forms a network of capillaries around the neck and body of the uriniferous tubule. Different useful substances from the nephric filtrate are reabsorbed in tubular part of nephron at different regions by both passive and active transport mechanisms.

The **proximal convoluted tubule** is responsible for the reabsorption of water, sodium, potassium, phosphate, bicarbonate and glucose. Water is reabsorbed by osmosis, while glucose and amino acids by active transport. Sodium ions are reabsorbed by both active and passive transport mechanisms.

Normally all the glucose is reabsorbed in the peritubular blood, so that the normal urine contains no glucose. But persons suffering from **diabetes mellitus, glucose** appears in the urine (a condition called glycosuria).

In **ascending limb of Henle's loop** NaCl is actively transported into medullary interstitial fluid from tubular fluid. This maintain high osmolality of interstitial fluid and low osmolality of tubular filtrate. This is called counter current mechanism. The distal convoluted tubules reabsorb remaining sodium and water against concentration gradient (i.e. by active transport mechanism).

3. Tubular Secretion

It includes movement of certain substances from the peritubular blood into tubular fluid. Urea, creatinine and very little uric acid and also K^+ and H^+ ions are secreted from blood in the tubular fluid in distal convoluted tubules and collecting ducts.

Regulation of Volume of Urine

Excretion of water i.e. the volume of urine excreted is mainly regulated by ADH (antidiuretic hormone).

1. Hormone Vasopressin secreted by posterior lobe of pituitary gland is antidiuretic. Its presence increases absorption efficiency of renal tubules.

2. **Hormone-mineralo-corticosteroid** and
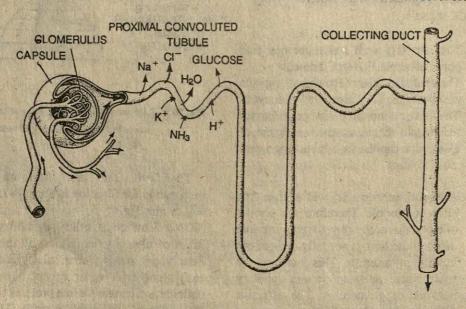
Fig. 20.10 Process in proximal convoluted tubule.
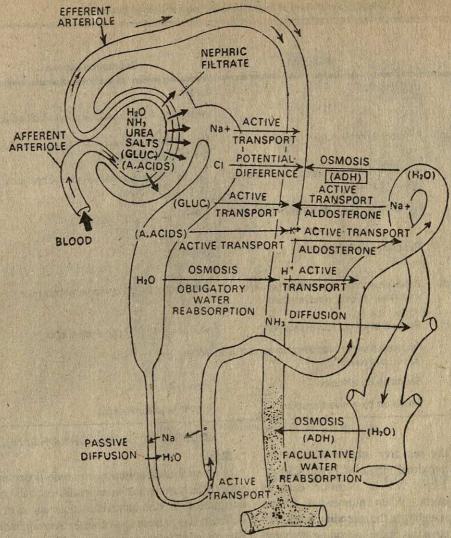
Fig. 20.11 Diagram showing functions of various parts of a nephron.

Glucocorticosteroid are secreted by adrenal cortex. These control amount of Na$^+$ ions and water in urine. Their deficiency causes increase of water and Na$^+$ in urine.

HOMEOSTASIS

Along with excretion, kidneys maintain *homeostasis* in the body by controlling amount of fluid, salts, nitrogenous wastes and ionic concentration in blood and extracellular (= or interstitial) fluid.

1. Regulation of fluid balance or Maintenance of osmotic pressure—The kidneys control osmotic pressure of extracellular body fluid by

regulating the amount of water lost from the body. If large amount of water is taken in, more water is eliminated by the kidneys. Vice versa, if large amount of water is lost from the skin or from the alimentary canal through vomiting or through diarrhoea and the loss is not compensated by a corresponding water intake, the kidneys will excrete a little amount of urine. This is brought about by reabsorption of water from the blood by Henle's loop. In terrestrial mammals, which produce concentrated urine, the loops of Henle are very long.

2. Regulation of electrolytes concentration. The concentration of electrolytes (sodium, potassium, chloride, bicarbonate) in blood is also

Table 20.1: Function of different parts of nephron in urine formation

Part of nephron	Function	Substance moved
Glomerulus	ultrafiltration	Water
		All solutes excepts colloids such as blood proteins
proximal tubule	Reabsorption by active transport	Na^+ and probably some other ions; nutrients—glucose and amino acids
	Reabsorption by diffusion (secondary to active transport)	Cl^-, HCO_3^-, and probably some other ions; also about 50% of urea
	Obligatory water reabsorption by osmosis	Water
Loop of Henle (a) Descending limb	Reabsorption by diffusion	NaCl
(b) Ascending limb	Reabsorption by active transport into interstitial fluid of renal medulla	NaCl (not followed by water reabsorption)
Distal and collecting tubules	Reabsorption by active transport	Na^+ and probably some other ions
	Facultative water reabsorption by osmosis (ADH controlled)	Water
	Secretion by diffusion	Ammonia
	Secretion by active transport	K^+, H^+, and some drugs

regulated by the selective tubular reabsorption mainly in the proximal tubule of Henle's loop.

Loops of Henle act as **counter current multiplier system.** When glomerular filtrate moves from descending to the ascending limb, Na^+ ions actively move out of the ascending limb and passively move into the descending limb. At normal rates of excretion all the Na^+ ions which are filtered out are later reabsorbed in the proximal tubule and are transported to the blood. The excess of Na^+ ions are secreted by the tubule from blood into the urine, thereby maintaining proper ionic concentration of the blood.

3. Maintenance of acid base balance—The kidneys play an important role in the maintenance of acid base balance in the body fluid by eliminating non-volatile acids, such as lactic acid, ketone, sulphuric acid and phosphoric acid. The sodium salts of these acids that are removed by glomerular filtrate are recovered by reabsorption in exchange for hydrogen ions.

ACCESSORY EXCRETORY ORGANS

1. Skin

In many aquatic animals, ammonia is excreted out into the surrounding water by diffusion through integument. In land animals integument is made impervious to prevent loss of water by evaporation. Human skin (also mammalian skin) possesses **sweat glands** and **sebaceous glands,** basically developed for temperature regulation by transpiration in former case and for lubrication in latter case.

(a) **Sweat glands**—These produce aqueous fluid called sweat. It serves to excrete water NaCl and traces of lactic acid, amino acids, urea and glucose.

(b) **Sweat glands**—Their secretion called sebum is wax-like and helps in elimination of waxes, sterols, fully acids and certain hydrocarbons.

2. Lungs

Lungs help in the elimination of carbon-dioxide produced in the body. Some moisture and some volatile materials are also lost by evaporation which are expelled out in the expired air.
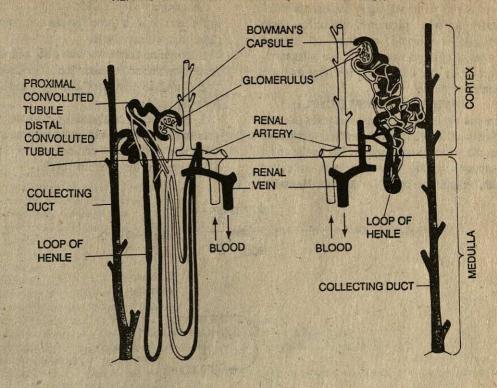
Fig. 20.12 Juxtamedullary and cortical nephrons.
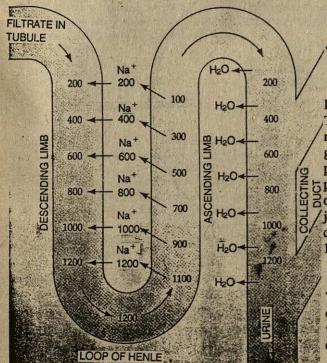
Fig. 20.13 Counter current concentration in loop of Henle.

JUXTAMEDULLARY AND CORTICAL NEPHRONS

Juxtamedullary nephrons have long Henle's loop. These extend deep into the medulla of kidney. Their malpighian capsulis and convoluted fubules remain in the cortex. The long Henle's loops creat a gradient of salt concentration in the medulla. In presence of **artidiurefic hormone** (which increase permeability of collecting duct), water is drawn out of the duct before urine enters the renal pelvis. The juxtamedullary nephrons conserve water and concentrate urine. In human kidney these are about 1/5th of total nephrons.

Majority of nephrons are **cartical nephrons**. These have small Herle's loop and are located in the cortical part only. These are primarily concerned with processing wrine in the tubule rather than coater retention.

3. Liver
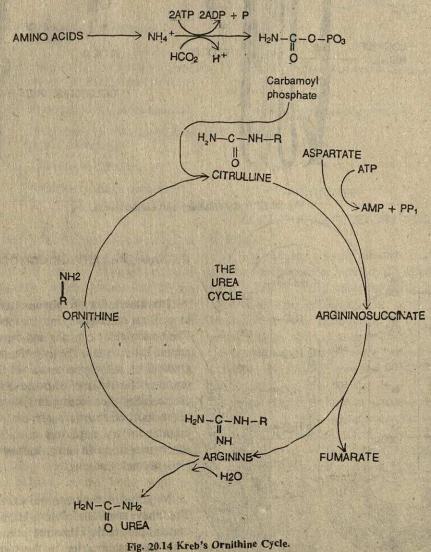
Liver is the principal organ for excretion of **cholesterol,** bile pigments (bilirubin and biliverdin), inactivated products of steroid hormones, drugs and vitamins. These substances are carried by the bile to the intestine and are eliminated with faeces.

ORNITHINE—ARGININE CYCLE

Formation of urea from ammonia takes place in the liver in collaboration with amino acid arginine in presence of enzyme **arginase.** The cyclic chain of reactions during urea formation is called 'Ornithine arginine cycle' or **Kreb's Henseliet**

Cycle

An important amino acid ornithine occurs freely in the liver cells. It forms the starting point in the chain of ornithine cycle.

1. Ornithine combines with NH_3 and CO_2 and forms citrulline and releases one molecule of water.

2. Citrulline combines with NH_3 and water to form arginine.

3. Arginine is catalysed by enzyme arginase present in the liver to split into **ornithine** and urea. Ornithine once again combines with NH_3 and CO_2 to repeat the ornithine cycle.

Fig. 20.14 Kreb's Ornithine Cycle.

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QUESTIONS

1. What do you understand by term excretion?
2. Describe internal structure of human kidney.
3. Describe structure of a nephron and physiology of its functioning.
4. Trace the path of a given molecule of water through kidney.
5. Describe role of liver and kidney in excretion of nitrogenous wastes.
6. What is ultrafiltration? How glomeruli act as ultrafilters of the body?
7. What is couter-current mechanism? How it is helpful in the maintenance of osmalelity of ECF.
8. Differentiate between aminotelism, ureotelism and uricotelisms.
9. Discuss role of kidney in homeostasis.
10. How are marine fishes of fresh water fishes able to maintain a specific osmotic pressure of ECF and a constant composition of blood?
11. Discuss role of kidney in maintaining acid-base balance in the blood.
12. Is urine acidic or alkaline and why?
13. Name the substances that occur as abnormal constituents of urine.
14. Differentiate between excretion and secretion?
15. Trace correlation between excretion and homeostasis.
16. What factors control volume of urine
17. Discuss how hormones control urine volume?
18. Explain the following
    (i) Ornithine—arginive cycle or Kreb's Hensleit cycle.
    (ii) Ultrafiltration.
    (iii) Deamination.
    (iv) Counter-current mechanism.
19. Name antidiuretic hormone. What is its function?
20. In a tabular form enumerate the role of each part of nephron in excretion?
21. What is dialysis of kidneys? Why it becomes essential for a person to get dialysis done?
22. If a person takes food rich in proteins and glucose, how is it going to influence composition of urine?
23. Sometimes urine is yellowish in colour. Why?
24. Draw neat and labelled diagram of a nephron of human kidney, showing its connection with renal artery and renal vein.
25. Differentiate between nephric filtrate and urine.
26. How does lungs and kidneys function as excretory organs? Name the substances they excrete.
27. Explain why frequency of urination more in winter than in summer.
28. What will happen if one of the two kidneys of man is damaged?
29. Match the following in column A with colum B

Column A	Column B
Nephridia	Insects (cockroach)
Nephron	Kidney
Malpighian capsule	Earthworm
Ammonotelic	Hydra
Uricotelic	Ultrafiltration

30. What is the difference between excretion and secretion?
31. Differentiate between urine and nephric filtrate.
32. How do excretion and egestion differ?
33. How does urine formation help in maintaining the correct composition of blood?
34. With the help of a labelled diagram name different parts of a nephron and mention their function.
35. What is ultrafiltration? How is it achieved in mammalian kidney?
36. What is the role of skin, lungs and intestine in the process of excretion?
37. Explain why the frequency of urination is generally more in winter than in summer.
38. What do you understand by ammonotelic, ureotelic and uricotelic animals? Give one example for each.

39. With the help of a labelled diagram describe structure of kidney in man.
40. What is excretion? Name various excretory products formed in the body of man. Describe briefly the process of their elimination.
41. Explain how animals dispose of the toxic ammonia formed as a result of breakdown of nitrogenous compounds.
42. What are the nitrogenous waste products? How are they got rid off from the body in different animals?
43. With the help of diagrams, describe renal excretory system in man.
44. How do lungs and kidneys function as excretory organs? Name the substances they excrete.

☐ ☐

Hormonal Coordination

The internal environment of animal body is maintained in steady state by autonomic **nervous system and the endocrine system.** The endocrine system brings about chemical coordination by complex organic compounds called **hormones.**

HORMONES

Hormones are **chemical regulators or chemical messengers** of body. These are also described as **informational molecules.** These are secreted in response to changes in the environment inside or outside body. The word **hormone** (G. *hormaein,* to exite) is derived from Greek word meaning 'I **arouse to activity.'** Hormones have following basic characteristics:

1. Hormones are produced in some organ and influence the functioning of some other organ.
2. Hormones are transported to the target organ by blood.
3. Hormones are required in very small quantity.
4. Hormones are highly specific in their action. Although, all hormones reach every part of the body each one of them influences only a specific organ/organs, called **target organ.**

Chemical Nature of Hormones

Animal hormones are organic substances of varying complexity that fall into two major classes.

1. **Steroid hormones**—These are Sex hormones (**estrogens, testosterone**) secreted by gonads and aldosterone, secreted by adrenal cortex.

2. **Amino acid derivatives**—These hormones are secreted by endocrine glands derived from embryonic ectoderm or endoderm. These may be formed of—

(i) **Glycoproteins**—Luteinizing hormone (**LH**), thyroid stimulating hormone (**TSH**) secreted by anterior pituitary

(ii) **Proteins**—Somatotrophic hormone (**STH**), follicle stimulating hormone (**FSH**) Lactogenic hormone (**LTH**).

(iii) **Polypeptides**—ACTH, MSH, ADH and parathormone, insulin and glucagon etc.

(iv) **Modified amino acids**—or **biogenic amines**—Thyroxin from thyroid gland; epinephrine and morepinephrin (catecholamines) from adrenal medulla.

Functions of Hormones

The presence of hormones in the blood and tissue fluid is essential for normal life, because cells work only if correct hormone in required quantity is present. In general, hormones control and coordinate following activities.

1. **Metabolic activities**—Some hormones control the rate of basal metabolism.

2. **Homeostasis**—Hormones maintain internal environment, regulate body temperature, water, ionic balance, and blood glucose level etc.

3. **Morphogenic activities**—Hormones control growth, development and differentiation of the body tissues of organisms; such as hormones of thyroid, pituitary and gonads.

4. **Mental activities**—Certain hormones influence the mental ability. The hypo-activity of thyroid gland results in mental retardation.

5. **Growth Maturation and Regeneration.** Growth, moulting, metamorphosis and even the regenerative activities and diapause etc. in various animals are controlled by specific hormones.

6. **Secondary sexual characters** and **Reproductive** activities—Hormones secreted by gonads produce secondary sexual characters and reproductive activities. For example, **testosterone** in male produces male characters and maturation

of sperm. The **progesterone** controls female secondary sexual characters, maturation of ovum, implantation of fertilized egg, its retention inside uterus and birth of young one.

7. Control of other endocrine glands. In certain cases, hormones secreted by one gland (hormones of pituitary gland) stimulate and control the secretion of hormones by other glands (thyroid, gonads etc.).

8. Adaptations. Adaptations to external factors (visual adaptation to light intensities, control of physiological colour changes) are regulated by hormones.

Table 21.1: Differences Between Vitamins, Hormones and Enzymes

Vitamins	Hormones	Enzymes
1. Animals are unable to synthesize vitamins. These are obtained from plants and form an important dietary requirement, except **Vit. D,** which is synthesized in the skin.	1. Hormones are synthesized in specific glands. These glands are called **endocrine glands.** The hormones are synthesized in one part and influence the function of some other part.	1. Enzymes are produced mostly at those places or in organs where these are used (for example digestive enzymes in alimentary canal or respiratory enzymes inside mitochondria).
2. Chemically vitamins may be organic acids, amines, amino acids, esters, alcohols and even steroids, but never proteins. For example	2. Hormones may be proteins, steroids, glycoproteins, ploypeptides or amino acid derivatives. For example	2. Enzymes are always proteins, either simple such as trypsin, chynopysis, amylase et. or conjugated.
(i) Vitamin A is a complex primary alcohol.	(i) **Thyroid stimulatin hormone(TSH)** of pituitary is a glycoprotein.	
(ii) Vitamin C (ascorbic acid) is an organic acid.	(ii)**Adrenocorticotrophc** hormone (ACTH) is a polypeptide.	
(iii) **Vitamin-B, (Thiamine)** is an amine	(iii) **Follicle stimulating hormone (FSH)** is a protein.	
(iv) Vitamin-B$_2$(Riboflavin)	(iv) **Thyroxin** is iodinated amino acid.	
(v) Nicotinamide is an acid amide.	(v) Hormones secreted by cortex are steroid (adrenocortico-steriods) and by gonads are also steroids.	
(vi)Pyridoxine B$_6$ and cobalamine (B$_{12}$) are amines. (vii) **Pantrothenic acid (B$_3$)** Biotin (B$_6$) and **Folic acid** are organic acids.	(vi) Hormones secreted by adrenal meduall are catechtamines.	
3. Vitamins act as coenzymes or their component with enzymes and help in catalysing various biochemical reactions, for example—	3. Hormones influence the functioning of specific genes and induce them to produce specific enzymes required during various metabolic and growth activites or modify the permeability of the	3. Enzymes act as biocatalysts that enable the cell to perform various chemical reactions at body temperature.
(i) Vit (B$_2$) (Riboflavin) is a component of coenzyme FMN (Flavin monoucleotide) and FAD (Flavin adenine dinucleotide) (ii) Nicotinic acid is a prosthetic group of coenzyme NAD (Nicotinamide adanine dinucteotide)		
4. The dietary deficiency of each vitamin produces specific deficiency disease. But excess of vitamins are excreted out.	4. Hormones are required in low concentration. Their excess as well as deficiency both produce marked disorders and diseases.	4. Enzymes are required in small quantities. These are most effective in higher concentration.

Vitamins	Hormones	Enzymes
5. These are consumed during the process.	5. It is not known whether hormones are consumed or not during reaction	5. Enzymes are not consumed in the reaction. These remain unchanged even after catalysing a number of reactions.

Endocrine Cell or Neurosensory Cell

↓

Hormonal
-The First Massenger

↓

Membrane Receptor Protein
or Plasma Membrane

↓

Prostaglandin

↓

Adenyl Cyclase

↓

Cyclic AMP ⟵——— ATP
The Second Messenger
↓
Specialized Cell
function

Fig. 21.1 Mechanism of hormone action and the postulated role of prostaglandin.

Prostaglandins (Tissue Hormones)

The prostaglandins (PGs) are a unique group of potent biological compounds (20-carbon fatty acids with 5 carbon-ring). These regulate endocrine activity at cellular level by influencing adenyl cyclase and cyclic AMP acitivty. Although, these may be secreted directly into blood stream like hormones, they are rapidly metabolized and inactivated.

Some day prostaglandins may find use in the treatment of such diverse diseases as hypertension, coronory thrombosis, asthma and ulcers.

There are three classes of prostaglandins:

1. Prostaglandin. A (PGA) help in regulation of blood pressure.

2. Prostaglandin. E (PGE) regulates RBC deformabilty and platelet aggregation; systemic inflammation and also incluences metabolic and gastro-intestinal functions

3. Prostaglandin. F (PGF) causes contraction of uterine muscles, induces labor pains and accelarates delivery; influences intestinal motility.

Mechanisms of Hormone Action

Nobel Prize Winner **Dr. Sutherland** has proposed **second messenger hypothesis** of hormone action. According to this concept—

1. Homone acts as **first messenger'**. It delivers its

THE FIRST MESSENGER

Membrane Receptor Protein on plasma membrane Prostglandin Adenyl cyclase

Cyclic AMP ATP

THE SECOND MESSENGER

Specialized cell function

chemical message from endocrine galnd to specific membrane-receptor sites on target cells.

2. On the cell membrane, hormone reacts with on enzyme, **adenyl cyclase**.

3. **Adenyl cyclase** catalyzes the conversion of ATP to cyclic AMP.

4. **Cyclic AMP** serves as the **'second messenger'** delivering information inside the target cells, that causes the cells to perform its specialized function.

ENDOCRINE GLANDS

Hormones are secreted by specialized glands These lack definite ducts for the transporation of their secretion but pour them directly into the blood. Therefore, these glands are called **ductless glands** or **endocrine glands** (glands of internal secretion) These are different from **exocrine glands** that have ducts by which their secretion is carried either to the body surface like skin or into the cavity like digestive tract.

HYPOTHALAMO—PITUITARY AXIS

Hypothalamus is part of forebrain. Its **hypothalamic nuclei** (masses of grey matter containing neurons) are located in the white matter in the floor of third ventricle of brain. Neurons of hypothalamic nuclei synthesize chemicals which are secreted into blood.

The venous blood from hypothalanus is collected by a portal vein. It passes through the stalk of pituitary and supplies the anterior lobe of pituitary gland. Here hormones of hypothalamus stimulate the cells of anterior pituitary to release various hormones. Hence these neurosecretions or hormones are called **'releasing factors'**.

1. Pituitary (Hypophysis) (The Master Gland)

Pituitary gland forms a link between nervous and endocrine system and maintains functional integration between the two. It exercises a regulatory influence on almost all the endocrine glands of body and hence is referred to as **'Master gland'**. The number of hormones secreted by pituitary is more than 13.

Position

Pituitary gland is attached to the under surface of forebrain by a stalk-like **hypothalamus**. It lies in the cavity of sphenoid bone, called **sella turcica**.

Structure

Pituitary is a rounded gland of the size of a large pea. Based on the origin, the pituitary is divided into two lobes;

1. Adenohypophysis - Anterior lobe.

2. Neurohypophysis - Posterior lobe and intermediate lobe

(A) **Adenohypophysis or Anterior lobe**—It forms 3/4th part of pituitary. It is derived from oral ectoderm as glandular diverticulum (The Rathke's pouch). Its secretory cells are arranged to form circular chains and are of two types (i) **Acidophils**

Table 21.2: Endocrine Glands in Man

Name of Gland	Location
1. Pituitary Gland	In head (On underside of fore brain)
2. Thyroid	In neck—(across the front of wind pipe)
3. Parathyroids (4)	- (One at each of the outer corners of thyroid)
4. Adrenals (2)	- In abdominal—(across the upper end of each kidney)
5. Thymus	
6. Gonads—(Testes and ovaries)	- In or below the pelvic cavity.
7. Placenta	Pregnant uterus.
9. Gastric and Intestinal mucosa	- In the abdominal cavity (in the wall of stomach and intestine)
10. Kidney	In the abdominal cavity kidney cell.
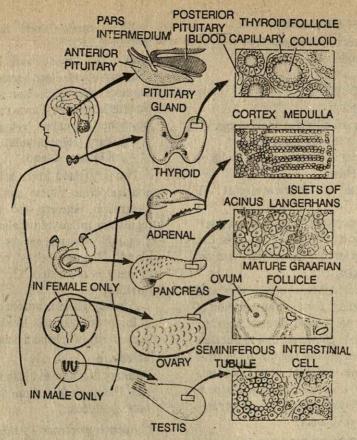
Fig. 21.3 Endocrine glands of man

secrete STH and prelactin (ii) Basophils secrete TSH, FSH, LH and ACTH

Adenohypophysis is connected with hypothalamms by a portal system of blood vessels (hypothalamo—hypophysial portal system). It secretes hormones which are either polyeiptides, proteins or glycoproteins. Based on the functional significance these are grouped into (i) **tropic hormones** and (ii) **gonadotropins.**

I. Tropic hormones

These activate other endocrine glands or target organ and are—

1. Somatotropic hormone or Somatotropin (STH or Growth hormone)—It enhences metabolic processes leading to body growth. It increases protein anabolism, fat-catabolism and decreases glucose-catabolism. It enchances cell division, growth of muscles, bones and connective tissue. STH influences growth of long bones. **Growth—hormone releasing factor** (GHRF) increases secretion of STH while growth-hormone inhibiting factor (GHIF) inhibits its secretion.

(a) Hyposecretion of STH causes following diseases—

(i) **Dwarfism**—Hyposecretion of growth hormone during childhood produces dwarfs. This dwarfness is described as **ateleiosis** and the dwarfs are called **midgets.**

(ii) **Pituitary myxoedema**—Hyposecretion in adult (i.e. after growth period) produces symptoms similar to hypothyroidism from hypoactivity of pituitary. Persons are weak with reduced genital orgns and reduced fertility. This disease is called **pituitary myxoedema.**

(b) Hypersecretion of STH causes following diseases—

(i) **Gigantism**—Hypersecretion of growth hormone during childhood produces long,

healthy and giant sized persons. These are called **pituitary giants.**

(ii) **Acromegaly**—Hypersecretion of GH in adult produces **dispropoitionate giants.** These have ugly face because of growth in the thickness of facial bones, long jaws and protruding forehead. This condition is called **acromegaly.** Sometimes a person develops hump due to bending of vertebral column. This is described as **kyphosis.** The hyposecrotion of leads to dwarfism while hyperactivity results in

2. Thyroid Stimulating hormone (TSH) or Thyrotropin

It stimulates thyroid gland to secrete thyroxine. Its secretion is controlled by thyrotropin-releasing factor (TRF) produced by hypothalamus. On hypophysectomy, TSH blood level falls causing thyroid atrophy, whereas its excess produces excess thyroxin.

(3) Adreno-cortico trophic hormone (ACTH)—

It controls normal functioning of adrenal cortex and release of mineralo-corticoids and glucocorticoids. Its hyposecretion causes atrophy of adrenal glands, and hypersecretion produces excessive growth of adrenal cortex.

II. The Gonadotropins

These tropic hormones control normal functioning of gonads and accessory reproductive organs. These are

(4) Follicle—stimulating hormone (FSH)—

In females FSH stimulates growth of Graafian follicle and secretion of estrogens by follictle cells. In males it controls formation of spermatozoa.

(5) Luteinizing Hormone (LH) in female and interstitial cell stimulating hormone (ICSH) in male. Luteinizing hormone (LH) stimulates vulation, formation of corps luteum and secretion of *progesteron and estrogens* from corpus luteum.

In male this hormone is called **interstitial cell stimulating hormone (ICSH).** It causes the secretion of **testosterone.**

Note—FSH and LH, ICSH are called **gonadutropins** or **gonadotropic hormones.** Their secretion starts during puberty, their secretion is controlled by *genetic biological clock* of hypothalamus

6. Prolactin or Lactogenic or Luteotropic hormone—It controls secretion of milk after delivery and during pregnancy promotes breast development. With LH it maintains corpus luteum late in the postovulatory or premenstrual phase. Its secretion is controlled by **prolactin hormons releasing factor (IRF).**

(B) Intermediate lobe

It secretes only one hormone known as intermedin or **melanocyte stimulating hormone (MSH).** It increases pigmentation or darking of the skin in many animals such as fishes, amphibians etc. In man it has no role.

(C) Posterior lobe or Neurohypophysis or Pars Nervosa

The posterior lobe of pituitary develops from the floor of fourth ventricle. It is connected with the hypothalamus by axons **(hypothalamohypophyseal tract).** Its secretory cells are called pituicytes. It secretes two hormones—

(1) Antidiuretic hormone (ADH) or Vasopressin—It is a water-retaining hormone. It discourges water loss by rapid reabsorption from tubular urine. It regulates electrolyte balance. The hyposecretion of this hormone leads to **diuresis** (abnormally large urine volume) and causes **diabetes insipidus. Its hypersecretion** produces **antidiuresis** (small urine volume).

(2) Oxytocin or Pitocin—It causes contraction of uterine muscles during child birth and ejection of milk from breasts during lactation. In male it helps in sperm transport and ejection.

2. Thyroid Gland

Position

Thyroid gland is situated in the neck just below larynx. Its two lobes lie one on either side of trachea and are connected by an *isthmus.*

Thyroid gland develops as an outgrowth of floor of pharynx.

Gland	Hormone		Chief functions	Effect of deficiency or excess
	Name	Abbreviation		
1. Hypothalamus	1. Thyrotrapin relesing factor	TRF	Stimulate anterior pituitary to secrete TSH	
	2. Corticotropin	CRF	Stimulates a nterior pituitary to secrete ACTH	
	3. Somatostatin		Inhabits secretion of GH from Anterior pituitary	
	4. FSH releaseing factor and LH releasing factor	FSH-RF LH-RF	Stimulates anterior pituitary to secrete FSH and LH	
	5. Prolactin releasing factor	PRF	- do -	
	6. Growth hormone releasing factor	GH-RF	Controls the release of growth hormone from anterior pituitary	
2. Pituitary Gland (A) Anterior Pituitary (Adenohypophysis)	1. Thyrotropic hormone or Thyroid stimulating hormone	TTH or TSH	Stimulates Thyroid to secrete thyroxin	
	2. Adrenocorticotropic hormone	ACTH	Stimulates adrenal cortese to secrete steroid hormones (corticosteroids).	
	3. Growth Hormone	GH	Stimulates body growth and cell metabotism.	Dwafrism, gigantis.
	4. Folliclestimulating hormone	FSH	i(In males - stimulates spermutogenesis ii) In female - stimulates maturation of Graafian follicle and secretion of estrogens from ovary	
	5. Luteinizing hormone (In Female)	LH	In female - with FSH causes completion of maturation of follicli, ovulation, formation of corpus luteum, secretion of progresterone from corpus luteum.	
	Interstitial cells stimulating hormone (in male)	ICSH	In male - Stimulated interstitial cells to secrete testosterone	
	6. Prolactin or (Lactogenic hormone)	—	Stimulates milk secretion from mammary glands after child birth	
(B) Intermediate lobs or Pituitary	Melanocyte stimulating hormone or intermedin	MSH	Conrols skin pigmentation in frog	
(C) Posterior pituitary (Neurohpophysis)	1) Oxytcin		Stimulate contraction of uterine muscles and release of milk from mammany glands	
	2) Vasoprossin (antidiuretic hormone	ADH	Stimulares water reabsorption by distal and collecting tubules and reduces water loss in urine	Increased or reduced water excretion.

3. Thyroid Gland	1) Thyroxin		Increases cell metabolism and energy, production, regulates growth and sexual maturity	Hypo-effect causes simple goitre Hyper-effect causes exophthalmic goitre
	2) Calcitonin		Decreases ca-ion concentration in blood	
4. Parathyoid glands	Parathormone hormone	PTH	Increase blood ca-and accelerates excretion of phophate	Hypo-action causes nerve and muscle abnormality, tetanus-like condition hyper activity causes hypercalcemia
5. Adrenal Glands (A) Adrenal Cortese	1) Glucocorticoids (Cortisal and corticosterone)		Accelerates tissue prtein mobilization and gluconerogesis from proteins; raises blood glucose level; promots fat utilization; helps to overcome norepinephrine's vasoconslricting effect.	Hypoactivity causes loss gluco - neogenesis and more oxidation of glucose. Hyperactivity causes impaired carbohydrate metabolism.
	2) Mineralocorticoids (aldosterone)		Increases sodium reterition and potassium elimination and water retentions.	Hypo-activity causes loss of sodiumions, Hyper-activity leads to impaised salt balance.
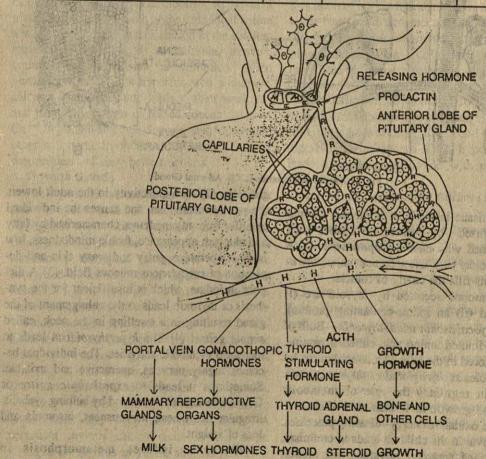
Fig. 21.4: Hormones secreted by anterior pituitary and their control by hypothalamous.
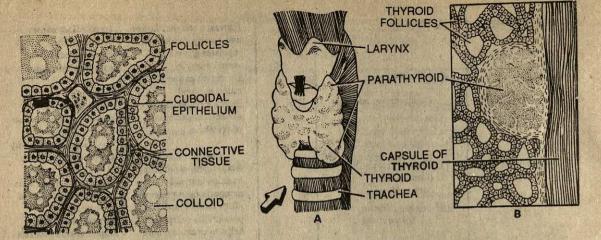
Fig. 21.5: T.S. Thyroid gland

Fig. 21.6: B.T.S. parathyroid gland

Fig. 21.7 A. Adrenal glands R.T.S. Adernal Gland

Structure

Thyroid tissue is made of numerous *thyroid follicles* pported by connective tissue. Each follicle is lined with *cuboidal epithelium* which secretes colloidal jelly-like secretion, called *thyroglobulin*. This fills the cavity of follicle.

The hormones secreted by thyroid are (i) *thyroxin* and (ii) an iodine-containing protein), and (iii) *thryocalcitonin triodothyronin*—Both of them are iodinoted amino acid called thyronine. These are stored in the jelly-like colloid in the lumen of follicles as *thyroglobulins thryocalcitonin*.

Thyroxin regulates the rate of metabolic activities and growth. Its fundamental effect is to speed up the oxidative energy-releasing processes. (1) Its removal in the children leads to cretinism, a condition of retarded physical and mental development and delayed growth of external genitalia. (2) Its hypoactivity in the adult lowers the rate of metabolism and causes the individual to suffer from myxoedema, characterised by fatty and sluggish appearance, feeble mindedness, low body temperature, puffy and waxy skin and deposition of subcutaneus mucous fluid. (3) A diet poor in iodine, which is insufficient for the synthesis of thyroxin leads to the enlargement of the gland resulting in a swelling in the neck, called *simple goitre*. (4) The *hyperthyroidism* leads to increased metabolic activities. The individual becomes highly nervous, overactive and irritable. Sometimes it leads to *expothalmic goitre* or **Grave's disease** characterised by bulbing eyeballs, irregular heart beat, nervousness, insomnia and loss of weight.

Thyroxine induces metamorphosis in frog tadpole. If thyroxine is administered in young

tadpoles, they metamorphose into tiny frogs prematurely, vice versa, if tadoples are fed on antithyroid substances (like thiourea) the tadpole continues to grow without metamorphosis.

Hormone calcitonin regulates metabolism of calcium and phosphorus ions. Calcitoniñ is secreted by some cells of thyroid outside thyroid follicles. Calcitonin is secreted only when concentration of Ca^{++} rises in blood plasma. It reduces their mobilization from bones.

3. Parathyroid Glands

The parathyroid glands are usually four small rounded bodies of the size of small peas which lie embeded in the dorsal surface of the thyroid gland. But these vary in number from 2—6 and develop from the gill pouches. The cells form strands and lie in the colloidal substance.

The hormone secreted is known as parathormone which exerts a major influence on calcium and phosphorous metabolism. Removal of glands results in the death of the individual within a weak due to disturbances caused in the calcium metabolism which leads to muscular tremors, cramps and convulsion, a condition called *parathyroid tetany*. Its hyperfunction withdraws calcium from bones and leads to their weakness and pain. This causes increased concentration of Ca^{++} in plasma and their deposition in kidney and other soft parts. In children, it produces skeletal deformities and easy bone fractures.

4. Thymus Glands

The thymus glands are paired structures present one on either side of trachea These persist throughout life in some mammals but in others these gradually decrease in size after puberty and sometimes disappear altogether. These are composed of lobules bound together by areolar tissue. The removal of glands at any stage of life cuases no apparent effect.

Since the gland decreases in size as sexual maturity increases, it is believed that it has some effect on the stages of growth and differentiation. It is also said to absorb gonadotrophic hormone and thus prevents development of gonads. Hypertrophy of this gland causes serious metabolic disturbances and even sometimes death. A persistant thymus causes death of the adult. Removal of thymus in young animals results in the production of fat and of disturbances in skeleton formation.

5. Adrenal or Suprarenal Glands

These are ocated on the top of each kidney. Each consists of two distinct parts : an outer cortex and inner medulla. The former develops from the mesodermal cells which aid in the formation of kidney and latter is derived from the sympathetic system. Each part secretes its independent hormones

A. Hormones Secreted by Adrenal cortex: Adrenal cortex secretes about 50 steroid hormones, collectively known as adreno-cortico steroid hormones. These fall in three categories (i) Glucocorticoids—influence carbohydrate, fat, and protein metabolism.

(ii) Mineralocorticoids—control metabolism of Na^+ and K^+ ions and water balance. Aldosterone is the main mineralocorticoid in man. It reduces elimination of Na^+ but increases K^+ elimination. Retention of Na^+ in blood increases absorption of water from urine and increases blood volume.

(iii) Sex-steroids—influence functioning of sex organs and development of accessory sex characters. Some of the common cortico-hormones are—cortisone, corticosterone, aldosterone, androsterone and oestradiol. Insufficiency of cortisones results in Addison's disease characterised by bronzing of skin, muscula weakness, low blood pressure and digestive disturbances, while hyperfunctioning leads to cushing syndrome with excessive fat deposition.

B. Hormones Secreted by Adrenal Medulla

Adrenal medulla secretes two hormones—1. Epinephrine or adrenalin and 2. nonepinephrine or nonadrenalin. Both the hormones are catecholamines, and sympathomimetic. Both control the contraction of involuntry muscles including the muscles of heart and arteries. Epinephrine raises blood pressure by raising cardiac output, stimulates conversion of glycogen into glucose and glucose metabolism and increases oxygen consumption, raises body temperature and causes excitation. Epinephrine rises diastolic blood pressure by vasoconstriction.

6. Hormones secreted by Sex Glands

Both testes and ovaries, in addition to producing sperm and ova also produce hormones. These are called sex hormones whih are responsible for the development of gonads and appearnce of secondary sexual characters. Chemically, these are

steroids.

(A) Testes—The interstitial cells of testes produce male sex-hormones, the **androgens** and **testosterone**. The deficiency of testo-sterone results in poor development of genital organs, overgrowth of long bones, absence of secondary sexul characters and sterility.

(B) Ovaries—The female sex hormones are
(i) **Estrogens**—These are secreted by th follicular cells of developing Graafian follicles and by the cells of placenta. These hormones induce estrous cycle and helps in the maintenance of secondary sex characters and accessory sex-oi gans.
(ii) **Progesterone**—It is secreted by corpus luteum and placenta. It controls final changes in uterine wall, brings about attachment of embryo to uterine wall, maintains pregnancy, and induces proper functioning of breasts.

7. Hormone Secreted by Islets of Langerhans in Pancreas

Embedded in the connective tissus between the pancreatic obules are the islets of Langerhans, which represent the endocrine portion of pancreas. These secrete two hormones, 1. Insulin—This in association with adrenal glands governs the metabolism of carbohydrates. It prevents overproduction of glucose from glycogen by the liver cells and enhances its conversion into glycogen which can be stored in the liver. The hyposecretion reduces the efficiency of liver to convert glucose into glycogen and its storage. Hence, the concentration of suger in blood increases and is excreted in the urine. This leads to a disease *diabetes mellitus*, characterised by steady loss of weight due to continuous loss of sugar, increasing weakness and ultimately death.

8. Hormones Secreted by the Digestive Tract

(A) Stomach wall produces a hormone gastrin that stimulates gastric glands of stomach to release gastric juice.

(B) The mucous membrane of duodenum produces six hormones.
(i) **Enterogastrone** that inhibits gastric glands and stops gastric motility.
(ii) **Hepatocrinin** stimulates liver to secrete bile juice.
(iii) **Cholecystokinin** causes contraction of gall bladder so that the bile juice is released in the duodenum.
(iv) **Secretin and pancreozymin** stimulate pancreas to secrete pancretic juice.
(v) **Enterocrinin** stimulates intestinal wall to secrete intestinal juice.

Neuro-Endocrine Integration

The **neuro-endocrine systems** (nervous and endocrine) function to achieve and maintain omeostasis (stability of internal environment). It is achieved by (i) communication, (ii) integration and (iii) control. But the mechanism of working of the two systems is different. These differences are shown in the table below

Nervous System

1. Messengers are conducted through **nerve impulses**. These are **electro chemical** in nature.
2. Nerve impulses pass through neurons from one specific sense organ to brain and from there to some other structure.

3. Nerve impulses produce swift short-lasting responses.

4. Nerve impulses control directly only two kinds of cells—muscles and gland cells.

Endocrine System 1. Control is exercised by hormones Hormones are specific chemical messangers. 2. Hormones circulate through blood to all parts of the body, but influence only the target organ. 3. Hormones produce slower and long-lasting responses. 4. Some hormones influence all the body cells (growth hormones), while others are highly specific.

QUESTIONS

1. What are endocrine glands? How are they different from other glands of the body?
2. Compare the activity of nervous and endocrine systems in communication integration' and control of body functions.
3. Explain the second messenger hypothesis of hormone action.
4. What is 'feed back inhibition or negative feed back system'? Explain with example.
5. Give differences between regular hormones, regulatory chemicals and prostaglandins.
6. What are prostaglandins? How do they function?
7. List the three classes of prostaglandins.
8. List the four trophic hormones secreted by pasophils of anterior pituitary.
9. Which of the trophic hormones also called gonadotropins?
10. What are hormones? Give their chemical nature.
11. What do you understand by target organ?
12. Describe similarities and differences between hormones and enzymes.
13. Name the hormone or hormones that help to control the following :
    (i) Blood sugar level.
    (ii) Ca-ion concentration in blood.
    (iii) Excretion of sodium ions.
    (iv) Blood potassium ion level.
    (v) asoconstriction.
14. What is the difference between diabetes mellitus and diabetes insipedus?
15. Discuss importance of hypothalamus in hormonal control.
16. Why pituitary gland is called master gland?
17. List the hormones secreted by pituitary gland.
18. What are releasing hormones? What is their chemical nature and how are they secreted?
19. Identify the endocrine gland which secrete eah of the following hormones :
    (i) Oxytocin (ii) Glucagon (iii) Calcitonin (iv) Growth Releasing factor
20. The following abbreviations stand for
    (I) ADH (ii) LH (iii) TRF (iv) FSH—RF (v) ACTH (vi) ICSH (vii) TSH
21. Discuss the role of hormones secreted by each of the cell types of islets of Langerhans.
22. Compare the physiological effects of insulin and glucagon.
23. What are the effects of epinephrine and nor epinephrine? Which endocrine gland secretes them?
24. What homone enhances and prolongs sympathetic effects? 25. Discuss the functions of following hormones :
    (I) Parathormone (iii) Gluco corticoid (ii) Pitucin (iv) Antidiuretic hormone
26. Which part of adrenal cortex secretes—cortisal or cortisone hormone.
27. Which hormone has anti-inflammatory effect?
28. Discuss the role of gonadotropins.
29. Which hormones maintain water and salt balance in the body.
30. Name the hormones secreted by pineal gland and discuss their importance.
31. Discuss hormonal role of placenta.
32. Discuss role androgens. Which androgen is most important.
33. Describe role of corpus luteum.
34. What is renin? Where is it produced?
    (i) Gigantism (ii) Acromeglay (iii) Dwarfism
35. Name the hormones that control the development of male and female secondary sexual characters.
36. Where are acidophils and basophils found? List the names of hormones secreted by them.
37. Tumour of which zone or layer of adrenal cortex would produce masculinizing effect?
38. Discuss the mechanism by which emotions or streas can influence all body functions.
39. When and where corpus luteum is formed?
40. Explain the relationship of growth hormone to following clinical conditions :
    (i) Gigantism (ii) Acromegaly (iii) Dwarfism
41. What factors are responsible for (i) Cretinism (ii) Myxedema (iii) Addison's disease
42. How will you identify that a person is suffering from myxedema?
43. Which hormone is called antidiuretic and why?
44. What do you mean by hormones and neurohormones?

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Nervous Coordination

To survive an organism must react to changes in its environment. This necessitates mechanisms for detecting such changes and translating these responses into appropriate actions. A means of rapid internal commuction is necessary which can collect stimulus/stimuli from **receptors** (= sense organs) present on the periphery and communicate them to the **effectors**. This process of **conduction of nerve impulses** and **integration** of activities of different parts of the body is carried out by nervous system.

Nervous system is basically an integrating and coordinating system. It carries out two main functions:

1. It regulates the internal environment of the body through its control of visceral organs.
2. It responds to the external environment of the body through various sense organs.

DIVISIONS OF NERVOUS SYSTEM

The nervous system is separated into following three sections

1. **Central nervous system (CNS)**—(i) **Brain** (Encephalon) and (ii) spinal cord (Myelon)
2. **Peripheral nervous system (PNS)**
    (i) Cranial nerves
    (ii) Spinal nerves.
3. **Autonomic nervous system (ANS)**
    Nerve fibres that innervate smooth muscles, cardiac muscles and glandular epithelium (i.e. autonomic effectors)

1. The Central Nervous System
BRAIN

Human brain is highly developed. In an average adult it weighs about 1,400 gms. It is encased in a bony case, **the cranium.** The cranium protects the brain from external injuries.

(A) Meninges

The brain is wrapped in three membranes called **meninges.** These are—

(i)   Outer **duramater** is a tough and protective layer formed of fibrous tissue. It lines the cranial cavity.
(ii) Middle **arachnoid** membrane.
(iii) Inner **piameter** is thin, transparent and vascular. It adheres to the brain.

(B) Spaces

(i)   **Subdural space** is the space between duramater and arachnoid.
(ii) Subarachnoid space is the space between arachnoid and piamater.

(C) Cerebrospinal Fluid

These sapces are filled with **cerebrospinal fluid.** It also fills the brain cavities or the ventricles. It is a slightly alkaline and clear fluid. It serves two functions

(i)   It maintains a constant pressure in and around the brain.
(ii) It forms a protective cushion to avoid bouncing of brain against the bony cranial surface and thus protects against shocks and mechanical injury.
(iii) It helps in exchange of nutrients and waste products between the nerve tissue and blood (acts as a lymph or tissue fluid).
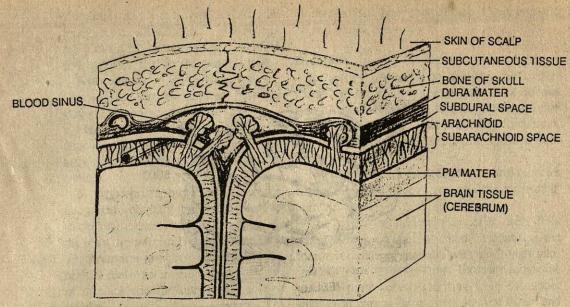
Fig. 22.1 Meninges of brain.

(D) Brain Matter

The substance composing the brain is differentiated into:

(i) **Grey matter** that forms the outer layer. It is formed of cell bodies (cytons) of neurons.

(ii) **White matter** that lies inside. It is formed of nerve fibres from the neurons.

(E) Divisions of Brain

1. Forebrain—(i) Cerebrum (telencephalon) (Prosencephalon) (ii) Diencephalon (thalamencephalon)

2. **Midbrain**—(iii) Corebral peduncle. (Mesencephalon)—(iv) Corpora quadrigemina

3. **Hindbrain** (v) Cerebellum (Rhombencephalon)—(vi) Pons (vii) Medulla oblongata

1. Cerebrum

The **cerebrum** is the largest and most prominent part. It is divided into right and left cerebral hemispheres by a deep median longitudianl groove. The two are connected together by a horizontal sheet of nerve fibres, called **corus callosum.** Each cerebral hemisphere is further divided by 3 deep issures into five lobes, namely: (i) **frontal lobe,** (ii) **parietal lobe,** (iii) **temporal** lobe (iv) **occipital lobe** and a small (v) **insula**

Cerebral Cortex

In cerebral hemispheres, the outer layer of gray matter is about 2—4 mm thick. It is called **cerebral cortex or neopalium.** It is formed of millions of neurons. Gray matter also forms islands in the white matter. These are called **cerebral nuclei.**
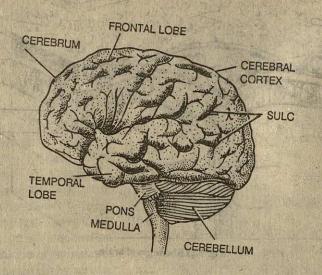
Gyri and Sulci

The cerebral cortex is highly convoluted. The ridges of these convolutions are called *gyri* and depressions between them as *sulci.* The convolutions enormously increase the surface area and the total amount of grey matter of hemispheres. The number and pattern of convolutions is associated with the degree of intelligente.

Functions

1. Cerebrum is the seat of highest mental faculties. It governs mental abilities like thinking reasoning, learning, memory, inteligence. It also controls will, emotions and speech.

2. Cerebrum is seat of conciousness but also exerts strong control over such reflexes as laughing, and weeping.

3. Cerbrum interprets various sensations or stimuli the specific regions of cerebral cortex are associated with specific senses, such as—

(i) visual area (ii) acoustic areas. (iii) Olfactory area (for taste and smell) (iv) Centre of speech :
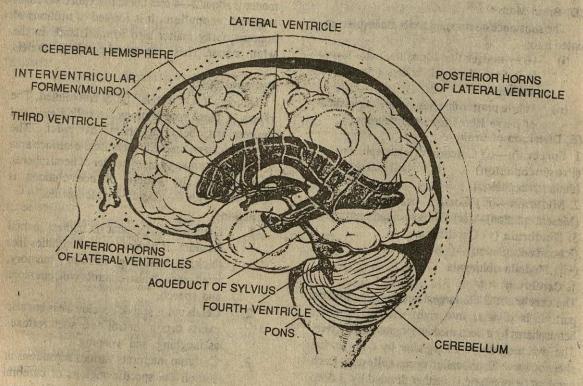
Fig. 22.2B Human brain sagital section.

4. Cerebrum respond to heat, cold, pain, touch, light and pressure. Their centres are located in the sensory areas, called someosthetic area in the parietal lobe.

Association areas in the frontal lobe are responsible for association between various sensations and movements.

Memory, intelligence and judgement depend on the coordinated and integrated activities of neurons of different cortical centres.

5. Appropriate motor impulses for integrated voluntary reactions are issued to skeletal muscles or to others parts of the brain, from **frontal lobes** of cerebrum.

(i) The **premotor area** in frontal lobes is the highest centre for involuntary movement of muscles and for autonamic nervous system.

Olfactory lobes (rhinencephalon) get incorporated with the enlarged cerebrum and are visible only in the ventral view.

2. Diencephalon

It lies between cerebrum and mesencphalon. Its cavity is called **third ventricle or diocoele**. **Thalamus, hypothalamus and neurohypophysis** (posterior pituitary) are associated with diencephalon.

(i) **Thalamus** consists of two round masses of gray matter bulging in the diocoele. It serves as a relay centre for sensory and motor impulses from spinal cord and brain stem to various part of cerebrum. Thalamus regulates manifestation of emotions and recognizes heat, cold and pain.

(ii) **Hypothalamus** forms the floor of diocoel. It is formed of pataches of gray matter of **neurosecretory cells** in the white matter. It serves following functions:

(a) It links nervous system to endocrine system and exercises a regulatory control on the functioning of endocrine glands by secreting *neurohormones*.

(b) It contains higher centres of autonomic nervous system controlling hunger, thirst, sleep, fatigue, emotions, satisfaction, anger, pleasure and penance.

(c) It also controls carbohydrate and fat metabolism, body temperature, blood pressure and water balance.

Midbrain

1. **Cerebral peduncles.** Midbrain has thick walls. These contain reflex centres and the thick **fibrous tracts**, called **cerebral peduncles** or *crura cerebri*. These tracts connect cerebellum with cerebrum, and transmit motor impulses to limb muscles from cerebrum.

Nuclei of some of these centres control **muscles tone** and modify some motor activities initiated in cortex.

The cavity of midbrain is called **iter**. It is represented by a narrow canal. It connects the fourth ventricle of medulla with third ventricle.

2. **Corpora quadrigemina.** These are four solid rounded protruberances arising from the upper sides of midbrain. These are centres of *visual* and olfactory reflexes.

Hindbrain

1. **Cerebellum.** It is the second largest part of the brain. It is located just below posterior part of cerebrum being partially overlapped. Like cerebrum its upper surface is formed of grey matter and forms **cerebellar cortex.** The deeper central part, the **medulla** is formed of white matter. **Cerebellar nuclei** of gray matter are scattered in the white matter. White matter contains **fibre tracts** connected with medulla and with thalamus or cerebrum. Cerebellum is partially divided into three lobes—

(i) Central part—called **vermis** and

(ii) two lateral lobes—called **lateral hemispheres.**

Functions

1. Cerebellum regulates and coordinates contraction of skeletal muscles.

2. It modulates and moderates voluntary movements initiated in cerebrum.

3. It maintains equilibrium, and controls posture.

4. It makes body movements smooth steady and coordinated.

2. **Pons.** It lies just above the medulla and is composed of thick bundles of white nerve fibres with few nuclei. Its nerve fibres connect the two cerebellum and thus coordinates muscle movements on the two sides of the body.
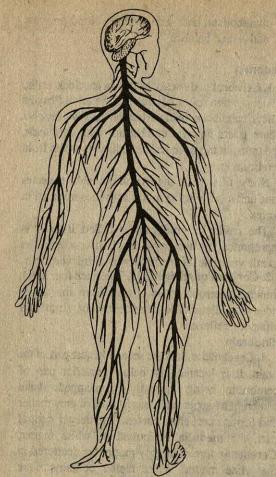
Fig. 22.3 Diagram to show spinal cord and spinal nerves of man

WHITE MATTER
PIAMATER
DORSAL SEPTUM
NERVE CELLS
DORSAL HORN
GREY MATTER
LATERAL HORN
VENTRAL HORN
VENTRAL FISSURE
CENTRAL CANAL
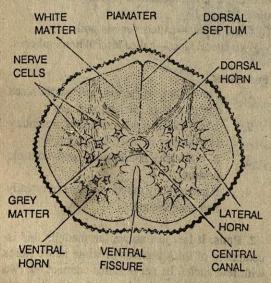
Fig. 22.4 T.S. mammalian spinal cord.

3. Medulla. It is the posterior part of brain and is also called **brain stem.** Its central cavity is called **fourth ventricle** or **metacoel.** The roof of metacoel is thin and contains a **cluter of blood capillaries.** These secrete **cerebrospinalfluid.**The side walls medulla are thick and formed of white matter. These contain nerve tracks, connecting the higher parts of brain with spinal cord. In its floor are present patches of gray matter, containing neurons. These are called **nuclei.**

Functions—The nuclei of medulla are centres of

(a) **Vital centres**

   (i)   **respiratory centres**—Control rate and depth of breathing.

   (ii) **cardiac centre**—controls rate of heart beat.

   (iii) **gastric centre**—controls flow of gastric juices.

(b) **Reflex centres**

   (i)   **Swallowing centre**—controls act of swallowing.

   (ii) **Vomiting centre**—controls act of vomiting.

   (iii) **Choking centre**—controls act of choking.

   (iv) **Salivary centre**—controls salivation.

(c) **Medulla** acts as a pathway conducting impulses from spinal nerves to spinal cord to brain.

SPINAL CORD

Location

Spinal cord lies in the neural canal of vertebral column. It extends from medulla to lumbar region. Like brain, it is also protected by three meninges, spinal fluid and a cushion of adipose tissue.

Structure

Spinal cord is cylindrical with two swellings—one in cervical region and one in lumbar region. It gradually tapers and finally divides into a bunch of small nerves forming a structure known as **horse tail** or **filum terminale.**

The central canal of spinal cord is continuation of fourth ventricle. It is filled with **cerebro-spinal fluid.** Two deep median grooves namely, **dorsal fissure** and **ventral fissure** divide the spinal cord into two symmetrical halves. Unlike brain, in spinal cord the grey matter forms the inner core. It appears **H-shaped** in cross-section and contains cell bodies of **association neurons** or **interneurons** and **motor neurons.** In cross section

of spinal cord, its grey matter appears to be penetrating into the white matter and forms horns on either lateral side. These are called **dorsal horns, ventral horns** and **lateral horns.**

The **white matter** surrounds the grey matter. In each half of spinal cord, the white matter is divided into three columns or **funiculi.** These are one anterior, one posterior and two lateral funiculi. Each funiculus is formed of **nerve tracts. A nerve tract** is a bundle of nerve fibres originating and terminating at similar sites. These contain ascending as well descending tracts.

1. **Ascending nerve tracts** conduct nerve impulses froms spinal cord to brain. The **sensory impulses** from the peripheral sense organs are brought to the spinal cord by sensory spinal nerves and from here through these tracts are conveyed to the brain.

2. **Descending nerve tracts** conduct impulses from the brain to different levels of spinal cord. The **motor impulses** from brain are transmitted to the cells of ventral and lateral horns of spinal cord. The axons of these cells conduct these motor impulses through spinal nerves to effector organs (glands and muscles).

Functions

Spinal cord performs sensory motor and reflex functions

1. It acts as a main centre of reflex actions.

2. It acts as a link between spinal nerves and brain. Thus it participates in concious actions.

PERIPHERAL NERVOUS SYSTEM (PNS)

Peripheral nervous system includes cranial and spinal nerves that connect the central nervous system with receptors and effectors of the body.

Nerve—A nerve is formed of several thousand **nerve fibres** enclosed in a connective tissue sheath. A *nerve fibre* is a long axon or dendrite of neuron. Some nerve fibres may be over a metre long. Each axon is filled with **axoplasm** continuous with the cytoplasm of neuron and is bounded by a thin membrane continuous with the plasma membrane of neuron. In some nerve fibres the axon is enclosed within a fatty **myelin sheath.** This is surrounded by a thin **neurilemma.** Neurilemma is the membrane of **Schwann cell** that lies in intimate contact with axon. The myelin sheath is interrupted at regular intervals (about one millimetre) by
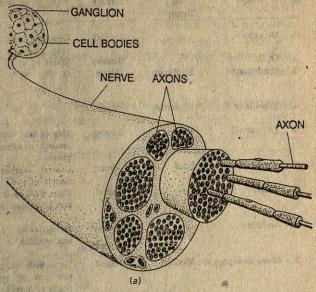
Fig. 22.5 Structure of nerve.

constrictions. These constrictions are called **nodes of Ranvier.** Based on the presence or abscence of myelin sheath nerve fibres are of two types

1. **Myelinated nerve fibres**—with myelin sheath.

2. **Non-myelinated nerve fibres**—without myelin sheath.

Afferent and Efferent Nerve Fibres

Based on the direction of propogation of nerve impulse through nerve fibre the neurons and nerve fibres are classified into **afferent** and **efferent** types:

1. **Afferent nerve fibres** conduct **sensory impulses** from the receptors present in the peripheral tissue **towards the central nervous system.** The cell bodies of afferent fibres are called **afferent neurons.**

2. **Efferent nerve fibres** conduct **motor impulses from central nervous system** to effectors. The cell bodies of these fibres are called **efferent neurons.**

Sensory and Motor Neurons and Nerve fibres

Based on the nature of impulse passing through the nerve fibre the neurons and nerve fibres may be

Table 22.1 Summary of Cranial Nerves of Man

S. No. Nerve	Origin from Brain	Nature	Origin of Sensory Fibres	Effector innervalid by motor fibres	Function
1. Olfactory		Sensory	Olfactory mucosa of nose.	---	Smell.
2. Optic		Sensory	Retina of eye.	---	Vision.
3. Oculomator	Midbrain	Motor	--	Four of the six eye ball muscles; ciliary muscles and eye muscles.	movement of eyeball; regulation of size of pupil; accommodation.
4. Trochlear	Midbrain	Motor		Superior oblique muscle of eyeball.	Eye movement.
5. Trigeminal	Pons	Sensory	Skin of face; teeth and mucous membrane of mouth.		Sensation of head; face; chewing movements.
6. Abducens	Pons	Motor	Lateral rectus of muscle of eye.	--	Abduction of eye; pro-priocaption.
7. Facial	Pons	Mixed	Taste buds of anterior part of tongue.	Superficial muscles of face, submaxilliary and sublingual glands.	(i) Facial expression six; (ii) Secretion of saliva; (iii) taste.
8. Auditory		Sensory	Semicircular canals and cochlea.	---	(i) Balance or equilib-rium and (ii) hearing.
9. Glossopharyngeal	Medulla	Mixed	Taste buds on poste-rior part of tongue, lining of pharynx.	Muscles of pharynx Pa-rotid glands.	(i) Taste (ii) Sensation (iii) Swallowing (iv) Secretion of saliva.
10. Vagus	Medulla	Mixed	Pharynx; Oesophagus Larynx; treachea tho-racic and abdominal viscera.	Same.	Visceral reflexes.
11. Spinal accessory	Medulla	Motor	Thoracic and abdomi-nal viscera	Muscles of neck and shoulder.	(i) Visceral reflexes; (ii) Shoulder movement.
12. Hypoglossal	Medulla	Motor	Tongue.	Muscles of tongue.	Tongue movements.

1. **Sensory neurons and nerve fibres** conduct sensory impulses from receptors or sense organs and evoke sensations like touch, pain, heat, cold, taste, smell, hearing or vision. Sensory neurons and nerve fibres are afferent in nature.

2. **Motor neurons and nerve fibres** conduct motor impulses to effectors i.e. muscle and glands etc. All motor neurons and nerve fibres are efferent in nature.

3. **Intermediate neurons or Association aneurons** connect sensory and motor neurons with each other and with other nerve cells in CNS. These are confined to CNS only.

Based on the type of nerve fibres it is composed a nerve may be—

1. **Sensory nerve**—It is formed of sensory nerve fibres only and conducts impulses from receptors to CNS to produce sensation.

2. **Motor nerve**—It is formed of motor nerve fibres only. It conducts motor impulses or orders from CNS to effectors to produce some reaction or action.

3. **Mixed nerve**—A mixed nerve is formed of both sensory and motor nerve fibres. Its sensory fibres bring sensory sypulses from receptors to CNS and motor fibres from CNS to effectors.

Nature of Nerves

A nerve is formed of several thousand nerve fibres.

CRANIAL NERVES

Twelve pairs of cranial nerves arise from brain in mammals. These are summerised in table 22.1

SPINAL NERVES

All spinal nerves are mixed type. Thirty one pairs of arise them from the spinal cord. These are

    (i) **Cervical nerves—8** pairs
    (ii) **Thoracic nerves—12** pairs
    (iii) **Lumbar nerves—5**
    (iv) **sacral nerves—5**
    (v) **coccygeal nerves—1** pair.

Each spinal nerve is a **mixed nerve.** It arises rom the spinal cord by two **roots.**

(i) The **dorsal root** is formed of only sensory or **afferent-nerve fibres.** It has a conspicuous swelling called **dorsal root gauglion.** The cell

dorsalis. It contains **somatic sensory, somatic motor** and **visceral motor** nerve fibres. Somatic sensory fibres bring sensory impulses from exteroceptors of skin and from proprioceptors present in the muscles, joints, tendons & ligaments. **Somatic motor fibres** innervate cutaneous and dorsal musculature. **The visceral motor fibres** innervate glands, smooth muscles of blood vessels etc.

(ii) The **ventral ramus** is longest and forms the spinal nerve proper. It is formed of somatic sensory, somatic motor and visceral motor fibres. These are connected with the similar receptors and
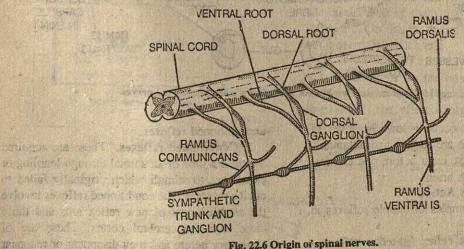
Fig. 22.6 Origin of spinal nerves.

bodies (cyton) of sensory neurons are located in the dorsal root ganglion. Sensory impulses from receptors to spinal cord travel through dorsal root of spinal cord.

(ii) The **ventral root** is formed of **motor nerve fibres.** The cytons of motor neurons are located in the ventro-lateral horn of gray matter. Their axons form the motor nerve fibre that emerge from the spinal cord in the ventral root of spinal nerve. These enter the glands and muscles in the peripheral tissue. Some ventral root fibres go to the skeletal muscles directly (**somatic motor fibres**) while others go to the autononic ganglia and end them. The two roots unite inside the vertebral column forming the spinal nerve. Each spinal nerve divides into three branches.

(i) A thin and short **dorsal ramus or ramus**

effectors in the lateral and ventral parts of body.

(iii) The **ramus communicans** is the shortest and thinnest branch and is connected with **autonomic nervous system.** It is formed of visceral sensory and visceral motor fibres. The visceral sensory fibres collect impulses from the interoceptors. The visceral motor fibres carry motor impulses from spinal cord to the ganglia of autonomic nervous system.

Relfiex Actions or Reflex Reaction

A reflex reaction is an immediate **involutary** response to a stimulus. In an involuntry response, a sensory impulse on reaching CNS is itself returned to a specific effector as a motor impulse without neuronal analysis and integration. This can be described as the simplest response.
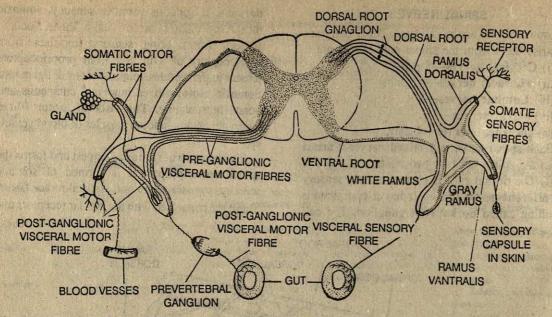
Fig. 22.7 Diagram showing kind of nerve fibres composing spinal nerves.

Reflex responses occur below the level of consciousness. These are sudden and automatic. These occur very fast, even before one can feel the stimulus through brain.

Examples of Reflex Action

The common examples of simple reflexes in man are :

1. The knee jerk reflex (patellar reflex)— When tendon of the knee cap is tapped, it stimulates the stretch receptors in the tendon and leg is involuntarily and momentarily straightened.

2. The ankle jerk (Achilles reflex)—It is the extension of foot in response to tapping of the Achillus tendon.

3. The quick closing of the eyelids or Blinking reflex—when an object approaches the eye.

4. Sneezing reflex in response to irritation of lining of nose.

5. Yawning in response to increased CO_2 in blood and skeletal muscles of face and thorax.

Types of Reflexes

1. Unconditioned reflexes—These are inborn, uncleared and unconscious responses to given stimuli.

These are inborn reflexes transmitted through heredity. These are elicited in response to definite stimuli. The reflex arcs of unconditioned reflexes are constant. The examples cited above refer to unconditioned reflexes.

2. Conditioned reflexes. These are acquired during life time of an animal through learning or experience to stimuli which originally failed to elicit a reaction. The conditioned reflexes involve the establishment of new reflex arcs and those close into the cerebral cortex. These are of temporary nature and may disappear or reappear again.

Russian physiologist **Ivon Pavlov** demonstrated the occurrence of conditioned reflexes through experiments with dog. Normally, salivation occurs only when food stimulates the taste buds on tongue (unconditioned reflex). Salivation can also occur by the sight and smell of food. These involve conditioned reflex. **Pavlov** supplied an additional stimulus to dog by ringing the bell, whenever food was provided to it. In due course of time, the ringing of the bell at the time of lunch produced salivation even in the absence of food.

Reflex Arc

The structural and functional unit in a simple reflex is termed as **reflex arc**. In its basic form, a reflex arc is regarded to be simple nervous pathway connecting a receptor and an effector. It consists of following parts :
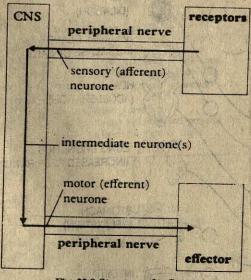
Fig. 22.8 Structure of reflex arc.

1. **Receptor**—It is represented by a single sensory cell or a group of cells, which receive stimuli.

2. **Afferent or sensory neuron**—It connects the receptor to the spinal cord. Its cell body is situated in the dorsal root ganglion of the spinal nerve. It conveys impulses from the receptor to the spinal cord.

3. **Association neuron or interneuron**—It is present in the spinal cord. It connects the afferent and efferent neurons and passes impulses from afferent to efferent neuron. Generally, there is only one association neuron in a reflex are but sometimes two of them may be present in one reflex arc. On this basis two types of reflex arcs have been differentiated

4. **Efferent or motor neuron**—It is situated with the ventral root of spinal cord. It transmits impulses to the effector organ which may be muscle or gland.

5. **Effector organ**—It responds to the impulses received and may be muscle or gland.
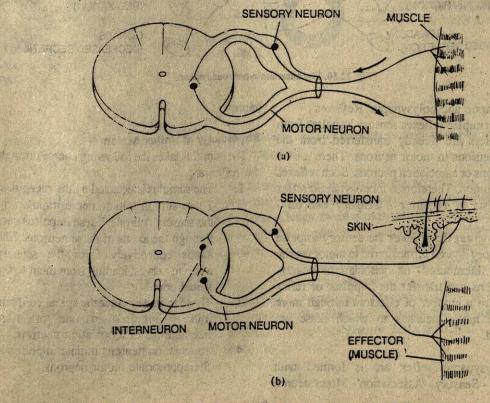
Fig. 22.9 Diagram showing monosynaptic and polysynaptic reflex arcs.

IRIS
(CONSTRICTION)

IRIS
(DILATION)

SALIVARY GLAND
(INCREASE OF SALIVA)

SALIVARY GLAND
(DECREASE OF SALIVA)

HEART
(DECELERATION)

HEART
(ACCELERATION)

LUNG BRONCHUS
(INCREASED RESPIRATION)

STOMACH
(EXCITATION)

STOMACH
(RELAXATION)

INTESTINE
(EXCITATION)

INTESTINE
(RELAXATION)

URINARY BLADDER
(CONSTRICTION)

URINARY BLADDER
(RELAXATION)

GONADS
(INCREASED SECRETION)

GONADS
(DECREASED SECRETION)

Fig. 22.10. The autonomic-nervous system .

Monosynaptic and polysynaptic Reflexes

In **monosynaptic reflexes** sensory impulses from the receptors are directly transferred from the sensory neurons to motor neurons. There are no interneurons or association neurons. Such reflexes are uncommon. Therefore a monosynaptic reflex arc consists of **receptor - Sensory neuron - motor.**

In **polysynaptic reflexes** the sensory impulse from sensory neuron is transferred to motor neuron through interneuron or association neuron. Interneurons can transfer the impulses of reflex response to a number of effectors through more than one motor neurons to which these are connected.

The polysynaptic reflex arc is formed with Receptor - Sensory - Association - Motor neuron

neuron

Physiology of Reflex Action

The stimulus takes the following course through the reflex arc :

1. The stimulus is detected by the receptors.
2. These stimuli initiate nerve impulses in the sensory neurons. These impulses pass through the axons of these neurons. The axons collectively form the sensory afferent nerves, leading from them to the spinal cord.
3. These impulses enter the spinal cord and initiate impulses in one or more interneurons or association neurons.
4. Association neurons initiate impulses in the appropriate motor neurons.

Table 22.2: Differences Between Sympathetic and Parasympathetic System

Sympathetic system	Parasympathetic system
1. Sympathetic fibres originate from cell bodies in the grey matter of spinal cord.	1. Parasympathetic fibres arise from cell bodies present in the brain and grey matter spinal cord in the sacral region.
2. Neurons of sympathetic fibres are situated in the sympathetic ganglia that form a chain along the ventrolateral side of vertebral column.	2. Neurons of parasympathetic fibres are situated in the effector.
3. Preganglionic fibres of sympathetic neurons are short.	3. Preganglionic fibres of parasympathetic fibres are long.
4. Postganlionic fibres of sympathetic neurons are long.	4. Postganglionic fibres are short.
5. Neuro transmitter released in the effector is **nonadrenalin** or **norepinephrine**.	5. Neurotransmitter released in the effector is **acetylcholine**.
6. Sympathetic fibres are called adrenergic.	6. Parasympathetic fibres are called cholinergic.
7. Sympathetic system accelerates activities and prepares the body against advense condition for fight or flight.	7. Parasympathetic system restores normalcy and provides feeling of relaxation, comfort and pleasure.
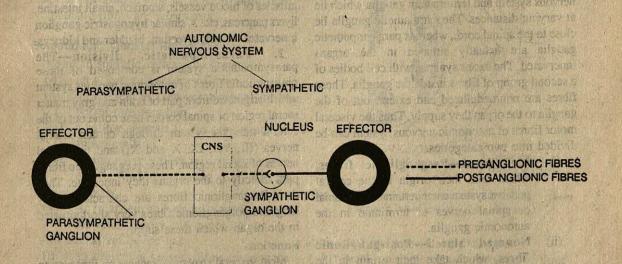
Fig. 22.11 Diagram to show difference between sympathetic and parasympathetic divisions of autonomic nervous system

5. When the impulses reach the junction between the motor neurons and the muscles or the glands (the effector) via motor or efferent nerve the latter are stimulated to discharge their function.

AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system is concerned with the maintenance and regulation of internal environment by controlling automatic activities of internal body organs whether we are asleep or awake. It controls the activities of heart, blood vessels, intestine, stomach, uterus, urinary bladder, lungs, sweat glands, salivary glands, gastric glands, liver pancreas, certain endocrine glands and other organs. It comprises visceral component and its ganglia and nerves arising from the ventral part of the spinal cord.

Autonomic nervous system is not nearly independent i.e. it is not fully autonomous. Its centres of control lie in the CNS.

Anatomy of Autonomic Nervous System

The autonomic nervous system consists of **visceral sensory and visceral motor fibres,** and their cell-bodies. The association neurons are absent. The **visceral sensory neurons** have beginning of their dendrites in the visceral organs, whereas the **cell bodies** are situated in the dorsal root ganglia. Therefore, the **dendrites** are long and extend from the organ innervated to the doral root ganglion. Their **axons** extend from the dorsal root ganglion to the grey matter of the brain or spinal cord.

The cell bodies of **visceral motor neuron** are situated in the grey matter of central nervous system. Their axons are short and formed of myelinated white fibres. These leave the central nervous system and terminate in ganglia which lie at varying distances. The sympathetic ganglia lie close to the spinal cord., whereas parasympathetic ganglia are actually situated in the organs innervated. The axons synapse with cell bodies of a second group of fibres inside the ganglia. These fibres are nonmedullated and extend out of the ganglia to the organ they supply. Thus the visceral motor fibres of autonomic nervous system can be divided into two categories.

(i) **Medullated—Preganglionic fibres,** which take their origin in the central nervous system enter certain of the cranial or spinal nerves to terminate in the autonomic ganglia.

(ii) **Nonmedutalated—Post-ganglionic fibres,** which take their origin in the autonomic ganglia and pass to the organs they innervate.

Divisions of Autonomic Nervous System

On the basis of anatomy and physiology, the autonomic nervous system is divided into two divisions:

1. **Sympathetic division**
2. **Parasympathetic division.**

1. Sympathetic division. The sympathetic nervous system consists of those autonomic nerve fibres which arise from cell bodies in the grey matter of spinal cord in the thoracic and loumbar regions. Their preganglionc fibres leave the thoraco-lumbar region of the spinal cord by way of the ventral root of spinal nerves and come out of it through **ramus communicans.** The ramus

communicans joins the sympathetic ganglion. In the thoraco-lumbar region these sympathetic ganglia form a complete chain on either side of ventral surface of the vertebral column. These are almost segmentally arranged. Each ganglion is connected with the ganglia in front and behind. Inside these sympathetic ganglia, the preganglionic fibres synapse with the potganglionic fibres.

The **potganglionic fibres** are long and leave the sympathetic ganglion. Some of them extend a short distance and rejoin the ventral root of spinal nerve by way of *grey ramus* and are distributed to the effector organs by way of spinal nerves. But the potganglionic fibres in the lower thoracic and upper lumber region form large **coeliac and anterior mesenteric ganglia** which innervate unstriated muscles of blood vessels, stomach, small intestine, livers pancreas, etc. A similar **hypogastric ganglion** innervates the colon, rectum, bladder and kidneys.

2. Parasympathetic division—The parasympathetic system is composed of those preganglionic fibres of autonomic nervous system which originated from part of brain and gray matter sacral region of spinal cord. These come out of the central nervous system through certain cranial nerves (III, VII, IX, X and XI) and the spinal nerves of sacral region. These preganglionic fibres pass directly to the organs they innervate. Thus their Preganglionic fibres are characteristically long and potganglionic fibres very short situated in the organ which these supply.

Functions

Most visceral structures receive an innervation from both divisions of the autonomic system (the sympathetic and parasympathetic divisions). The two systems are antagonistic in their actions on most visceral organs. The **parasympathetic nervous system** is associated largely with the activities concerned with normal body functioning. It represents the nervous mechanism by which visceral organs respond to natural unconscious stimuli, for example, ingestion of good results in increased gastro-intestinal secretions and movements. The sacral parasympathetics are concerned chiefly with the evacuation of bladder and the rectum and with the control of accessory organs of reproduction. The terminals of the post ganglionic fibres of parasympathetic fibres liberate the chemical substance **acetylcholin** at their endings and this substance acts upon the effector

organs. These fibres are called **cholinergic.**

The **sympathetic system** is chiefly concerned with protective responses in times of emergency. For example, in the presence of danger, the sympathetic nervous system leads to the forward dilation of the nostrils, increase in the rate of breathing, stoppage of perislatic movements, closure of sphincter, erection of the hair, constriction of the peripheral blood vessels etc. Thus sympathetic system prepares the animals for 'fight or flight'. Parasympathetic system on the other hand tends to counteract the effect of sympathetic system and for restoring to normalcy.

The neurotransmitter released into the innervated effectors at the end of sympathetic fibres is **norepinephrine** or nonadrenaline. The sympathetic fibres are **adrenergic.**

Somatic and Visceral Reflex Arc

A simple **somatic reflex** arc consists of
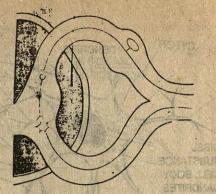
(i)   an afferent or **sensory fibre**
(ii) an afferent or (**sensory neuron**) in the dorsal root ganglion
(iii) a **motor neuron** in the grey matter of spinal cord
(iv) a **motor nerve fibre** arising from motor neuron and innervating the effector directly.
(v)   An **interneuron** forming synoptic contact between sensory and motor neuron.

A Visceral reflex arc has

(i)   an afferent or **sensory fibre** entering the spinal cord through dorsal root.
(ii) an **afferent** or **sensory neuron** in the dorsal root ganglion.
(iii) **Preganglionic neuron** (not motor) in gray matter of spinal cord.
(iv) Its nerve fibre called preganlionic fibre leaves spinal cord through ventral root.
(v)   Preganglionic fibres communicates synaptically with another neuron (postganglionic neuron) located outside CNS.
(vi) Postganglionic neuron innervates the effector.

HISTOLOGY OF NERVOUS SYSTEM

The basic structural and functional unit of nervous system is a **neuron** or **nerve cell.** These act as **electrical capacitors** or condensers. These

SOMATIC REFLEX ARC

POSTGANGLIONIC NEURON

PREGANGLIONIC NEURON

VISCERAL REFLEX ARC
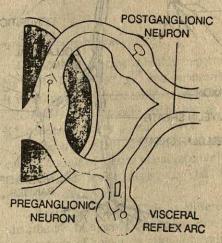
Fig. 22.12 Diagram to show the differences between somatic reflex and visceral reflex arc.

accumulate and store electric charges.

A typical multipolar neuron consists of three parts—

1. Cell Body or Soma—It is also called cyton. Its cytoplasm contains **Nissil granules** which are darkly stained regions of cytoplasm rich in rough endoplasmic reticulum (RER) and ribosomes.

2. Dendrites.— These are highly branched extensions of cytoplasm. These are specialized to receive stimuli.

3. Axon—This is single long cytoplasmic extension of variable length. It may be as long as 2 meters or more in some animals. Axon arises from a thickened area of cell body, the **axon hillock.** At its distal end, axon branches profusely and each branch ends in a tiny enlargement called **synaptic knob.** The synaptic knob lies in contact with adjacent neurons and form synapse. It releases **neurotransmitter** that transmit impulses from one neuron to other. Axon-forms the nerve fibre.
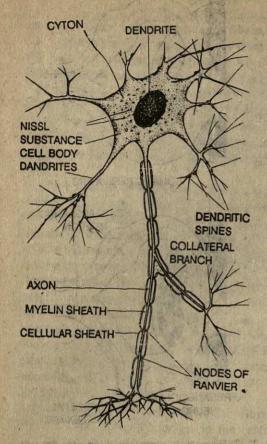
Fig. 22.12 Structure of multipolar neuron

Axons of peripheral neurons are enveloped by a cellular sheath-formed of **Schwann cells.** This is called neurilemma.

The cellular sheath helps in regeneration of injured nerves.

Nerve and Ganglia
A nerve is formed of hundreds or even thousands of axons wrapped in connective tissue. Within CNS these bundles of axons are called tracts or pathways rather than nerves. The cell bodies of neurons are grouped together in masses, called ganglia.

Synapse
Each neuron is a discrete unit, Yet, by transferring impulses from one neuron to others, these form continuous transmission lines like electric wires. Impulses are transferred from one nerve cell to the other at junctions where the axon or Clendrile of one neuron (**presynaptic neuron**) terminates upon the cell bodies, dendrites or some other portions of adjacent neurons (**postsynaptic neuron**).These

junctions are called *synapse.* The term was derived by **Sherrington** from Greek word **synapsis**-conjunctions. However, the connecting neurons are separated by minute spaces called *synaptic clefts.* There are three types of synapses between the neurons—

1. **Axodendritic**—In axodendritic synapse the synaptic knobs at the tip of an axon are associated with the surface of a dendrite. Most synapses are of axodendritic type.

2. **Axosomatic**—In this synapse association is between axon of one neuron and soma of next neuron.
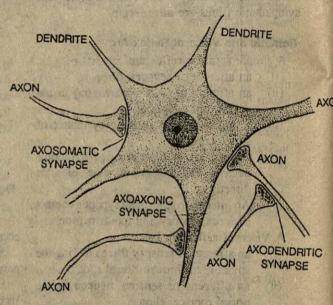
Fig. 22.14 Diagram showing three different tupes of synapses between neurons

3. **Axonic**—This synapse is between axons of two adjacent cells.

PROPAGATION AND CONDUCTION OF NERVE IMPULSE

Nerve Impulse
A nerve impulse is an electrochemical event which brings about change in the resting potential or membrane potential of the nerve fibre, which spreads rapidly down the fibre and causes transmission of stimulus from receptor to the CNS and from there to end organ or effector.
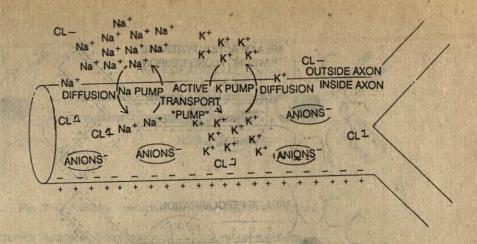
Fig. 22.15 Na^+ K^+ pump across the plasma membrane.

Conduction of Nerve Impulse

Conduction of nerve impulse is an electro-chemical event which involves the passage of measurable electric current along a nerve fibre and a few biochemical activities at the synaptic ends.

Electric Basis of Nerve Impulse Conduction

Like all other cells, the nerve cells exist in the fluid environment, called **extracellular fluid (ECF)** or **interstitial fluid**. In it are dissolved certain salts and ions, like Na^+, Ca^{++} and Cl.

The cytoplasm of neurons contains a number of dissolved amino acids and proteins. These are negatively charged (anions) and being large are unable to diffuse out of the cell. These make cell interior negative. Therefore the inner surface of plasma membrane is negatively charged.

Plasma membrane is quite permeable to K^+ ions. These tend to diffuse inside the neuron to neutralize the cells organic anions.

1. **Ionic distribution**—In a resting neuron the distribution of ions is as follows:

1. High concentration of Na^+, Ca^+ and Cl^+ outside the cell i.e. in the ECF.

2. High concentration of K^+ and organic anions inside the cell.

3. Na^+ are 10 times more numerous outside the cell and K^+ ions are 25 times more numerous inside the cell.

4. Plasma membrane is highly impermeable to Na^+, Cl- less so to Ca^{++} and permeable to K^+. It is altogether impermeable to organic ions.

5. Na^+-K^+ pump actively maintains Na^+ and K^+ concentration at a steady level.

6. Due to unequal distribution of anions and cations outside of plasma membrane is electrically positive and inside negative. This is called **potential difference**.

2. **Resting potential**—It is the difference in the distribution of electric charge between the inside and outside of a neurons plasma membrane. The potential difference maintained is about—70 to -90 millivolts (mv).

Propagation of Nerve Impulse

1. **Depolarization**—When a stimulus of any kind, mechanical, electrical or chemical impinges upon the nerve fibre, momentarily, a local increase occurs in the membrane permeability by opening sodium gate at the site of stimulus, which permits more sodium ions to rush into the cell. This is just the opposite of the resting state and is called **reverse potential**. It results in *depolarization* of the membrane and a local negatively charged area.

2. **Action potential**—This changed electric potential of the neurilemma is known as **action potential**. The initial change produces an ionic imbalance in the membrane on either side of the

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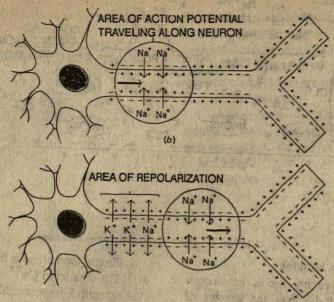
Fig. 22.16 Transmission of nerve impulse through nerve fibres.

point of stimulus producing local electric current. These areas of negative depolarization, in turn initiate changes in the membrane adjacent to them. A wave of electric changes or depolarization along the length of nerve fibre or axon is known as **nerve impulse.**

The propagation of nerve impulse can be compared to the pushing over of a row of dominoes. Energy is required for the initial disturbance, but after that the displacement of domino works to displace the next and once the stimulus has set off a nerve the impulse passes without any change down the length of the fibre.

3. Repolarization—With the increase of positive charge inside, further entry of Na^+ is prevented and permeability of membrane decreases and Na^+ ions are pushed out. With the establishment of sodium pump the inside of the membrane becomes negative and outside becomes positive and the membrane restores the original resiting potential. This is known as **repolarization.** The repolarization starts exactly on the **same spot** where depolarization had started and then continues to advance in both directions.
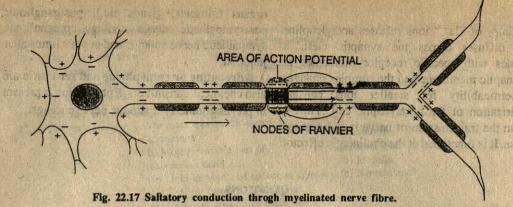
The entire process of repolarization requires some time during which the nerve cannot be stimulated again. This period is known as **refractory period.**

Threshold Level Stimulus

A very weak stimulus is unable to propagate a nerve impulse. Intensity of stimulus which is just adequate to cause an impulse is called the **threshold stimulus.** Stimulus below threshold causes a small membrane depolarization but **no** actin potential.

A. Transmission of Nerve Impulse through Medullated Nerve Fibres or Saltatory Conduction

In medullated nerve fibres the myelin sheath acts as an insulator. Ions cannot pass through the myelin sheath. The membrane at nodes of Ranvier is 500 times more permeable. The nerve impulse in these fibres passes from node to node along the entire length of nerve fibre. The depolarization jumps from one node of Ranvier to the next. This jumping of depolarization from node to node is known as **salutatory conduction.**

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Fig. 22.17 Saltatory conduction throgh myelinated nerve fibre.

Myelin sheath increases the speed of conduction and avoids dissipation of impulse into adjacent fibres.

B. Synaptic Transmission

Theory of Chemical Transmission

According to the theory of chemical transmission of the synapse, a specific chemical is synthesized by the tip of the axon and is released when nerveimpulse reaches it. It diffuses across the synatpci space and attaches to a special chemoreceptor on the surface of the dendrite of the adjacent cell. The combination of this chemical with the chemoreceptor leads to a change in the membrane which depolarizes it and sets up a new action potential. This passes along the length of the neuron to the next synapse where it stimulates the release of another chemical mediator. Thus between the action potential (the wave of depolarization) in one neuron and the action potential in the next neuron, there is interposed a mechanism involving the secretions of a specific substance by one cell and the combination of this with a specific chemoreceptor in the next cell.

Chemical transmission at the synapse involves two process (1) Neurosecretion The release, by the arrival of a nerve impulse, of the specific chemical from its storage space in the tip of the axon into the narrow space between the adjacent neurons, and (2) Chemoreception—In this process the specific transmitter substance is attached to specific molecular sites in the dendrite and produces a change in the properties of its cell membrane so that a new nerve impulse is set up.

Neurotransmitters

Neurotransmitters also known as 'neurohormones' or 'neurohumors' are special chemical substances contained in minute synaptic vesicles in the cytoplasm of synaptic knob. These on being released help in the transmission of nerve impulse to the postsynaptic neurons.

When an impulse reaches the synaptic knob at the end of the presynaptic axon' Ca^{++} ions diffuse into the knobs from surrounding tissue fluid. Ca^{++} ions initiate breakdown of synaptic vesicles and release of neurotransmitters in the tissue fluid of synaptic cleft. The neurotransmitter acts on the receptors on plasma membrane of postsynaptic cell and generates electrotonic potentials. The entire process, including diffusion of transmitter in the synaptic cleft and the propagation of nerve impulse in the postsynaptic neuron takes about half a millisecond or slightly longer (0.5-1.0 millisecond). This is called synaptic delay and led to the theory of chemical transmitter.

The arrival of action potentials at synaptic knobs produces a depolarizating excitatory postsynaptic potential (EPSP). The best known transmitters involved in generating EPSPs is acetylcholine (Ach).

Another type of postsynaptic potential hyperpolarizes the postsynaptic cell, making it more negative. This inhibits the generation of action potential and propagation of nerve impulse. This is called inhibitory postsynaptic potential (IPSP).

Acetylcholine

Acetylcholine is a chemical transmitter at the synapses. Depolarization of terminal knobs of axon causes local movement ions, of including Ca^{++}

ions. Entry of Ca^{++} ions releases acetylcholine which diffuses across the synaptic cleft. It combines with specific receptor molecules of postsynaptic membrane and the complex changes the permeability for smaller ions causing depolarization of the postsynaptic cell. Thus it helps in the transmission of nerve impulse at the synapse. It is functional at the cholinergic effector organs (muscles, glands etc.), postganglionic parasympathetic nerve endings, preganlionic sympathetic nerve endings and at neuro-muscular junction.

Adrenaline or epinephrine and **serotonin** are also chemical transmitters. Epinephrine is present in preganglionic sympathetic nerve endings.

QUESTIONS

1. Give an account of various parts of brain.
2. Describe the protective coverings of human CNS and give the function of cerebrospinal fluid.
3. Compare the effects of sympathetic and parasymbathetic nerves on heart, pupil, blood vessels and blood pressure.
4. Explain 'fight or flight' effect.
5. Describe a reflex are with a diagram.
6. Briefly describe the sympathetic nervous control on visceral organs.
7. Difference between Sonatic and visceral reflex arcs.
8. Differentiate between
    (1) monosynaptic and polysynaptic reflexes (2) Unconditioned and conditioned reflexes.
9. What do you understand by resting membrane potential and action potential?
10. Describe the biochemistry of resting membrane potential.
11. Describe mechanism of action potential and propagation of nerve impulse.
12. What is synapse? Explain various types of synapses found between the neurons.
13. Describe transmission of nerve impulse across the synapse.
14. Explain the following terms in brief—
    (1) Resting potential   (3) Polarization
    (2) Action potential   (4) Repolarization
    (5) Hyperpolariztion   (6) Saltatory conduction
    (7) Refrectory period   (8) Spike potential.
15. Fill in the blanks:
1. Sensory nerves enter the spinal cord through the _____ root.
2. The The medulla and pons make up the _____ .
3. The fourth ventricle called _____ is located within the _____ .
4. The _____ nerves transmit impulses towards (NS whereas the _____ nerves transmit them away from CNS.
5. As you answer these questions your brain should be emitting _____ waves.
6. In saltatory conduction, depolarization skips along the oxan from _____ .
7. When an impulse reaches the synaptic knob it stimulates the release of _____ .
8. Adrenergic neurons release neurotransmitter _____ at the synapse.
9. In some peripheral neurons, **Schwann** cells produce both a _____ and a _____ .
10. Functional connections between neurons are called _____ .
16. Explain summation and facilitation.
17. Differential between
    (i) Afferent and efferent neurons
    (ii) Adrenergic and cholinergic nerve fibres
    (iii) Preganglionic and postganglionic fibres
    (iv) Presynaptic and postsynaptic neurons
    (v) Receptors and motor end plate.
    (vi) Cerebrum and cerebellum.
    (vii) Resting potential and action potential
    (viii) Central and peripheral nervous system
    (ix) Sympathetic and parasympathetic system.

18. What is all and none law?
19. How sodium—potassium pumps contribute to resting potential ?
20. Describe functions of
    (i) Acetylcholine (ii) Cholinesterase
    iii) norepinephrine (iv) Myelin
    (v) Schwann cells
21. Contrast saltatory conduction with conduction in an unmyelinated neuron.
22. For each group select the most appropriate answer from folum B:

Column A	Column B
(i) Most prominent part of mammalian brain	(a) Meninges.
(ii) Links nervous and endocrine system	(b) Medulla
(iii) Shallow furrows between gyri	(c) Hypothalamus
(iv) Layers of connective tissue that protect CNS.	(d) Sulci
(v) Contains vital centre.	

23. Match the items in column A and B

Column A	Column B
(i) Cerebellum	(a) Spinal nerve
(ii) Sodium pump	(b) Muscle fibre
(iii) Motor and plate	(c) Posture and equilibrium
(iv) Dorsal root ganglin	(d) Manibrane potential Resting potential

24. What is the difference between preganglionic and postganglionic fibres? Discuss what is their distribution in sympathetic and parasympathetic nervous system.

25. Differentiate between modullated and nonmodullated nerve fibres.

☐ ☐

SENSE ORGANS

Sense organs are specialized structures formed of one or more **receptor cells** to perceive changes in their external and internal environments.

Receptors are either neuron endings or specialized cells that are in close contact with neuron endings to perceive information about their external or internal environment. The receptor cells receive stimuli from changes in the environment and transform these excitations into electro-chemical impulses. By sensory neurons these impulses are carried to the brain. Hypothalamus is the main and cerebral cortex is the secondary centre for the analysis of sensory impulses in the brain. Thus **awareness of stimuli resides in the brain, the receptors are merely a means of access to the nervous system.**

CLASSIFICATION OF SENSE ORGANS

A. **Classification Based on Position of Sense Organs**

1. **Exteroceptors** - These receptors are found at or close to the body surface and receive external stimuli such as heat, light, pressure and pain etc. These include -
   (i) **General** receptors or cutaneous receptors present in the skin.
   (ii) **Special sense organs** are photoreceptors or eyes, olfactoreceptors, auditory organs or ears and tangoreceptors or taste buds.
2. **Interoceptors or visceral receptors** – These receptors are located in the wall of blood vessels and all internal organs and occur as
   (i) **Naked nerve terminals** in visceral walls and adventitia of blood vessels.
   (ii) **Lamellated corpuscles** in heart, pancreas, mesenteries and adventitia of blood vessels.
   (iii) **Arborized terminals** in endocardium of heart, endomysium of muscles and in connective tissue.
   (iv) **Baroreceptors** (or pressure receptors) in the wall of blood vessels to regulate blood flow and pressure ; in the alveoli and bronchi etc. to control respiration.
3. **Proprioceptors** - These are scattered in the somatic or voluntary muscles, tendons and

joints. These receive somatic stimuli of movements, position and pressures in organs and
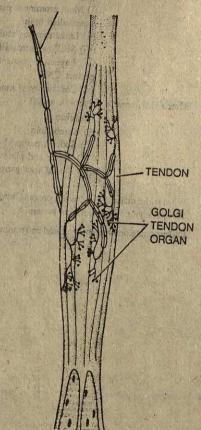
Fig. 23.1 Proprioceptor

structures of locomotion system.

SPECIAL SENSE ORGANS

Special sense organs are –
1. Eyes - Organs of vision
2. Ears - Statoacoustic organs
3. Nasal organs - Olfactoreceptors
4. Taste buds - Gustatoreceptors.

1. Eyes

Position

Human eyes are located in bony **orbital sockets** or orbital cavities and are cushioned in fatty connective tissue. For moving the eye ball in the orbit,

six extrisic musceles are attached to its surface. These are:

(i) anterior rectus   (ii) superior rectus
(iii) inferior rectus   (iv) posterior rectus
(v) superior oblique   (vi) inferior oblique.

Structure of Eye

Vertebrate eye is a fluid-filled rounded or globular sac called **eyeball**. Only one sixth of the eyeball projects out of the orbit. It is transparent and is called **cornea**. The wall of eyeball is formed of three concentric layers or coats.

1. **Sclerotic** - It forms a thick, tough and opaque capsule around the eyeball. It is formed of dense fibro-elastic connective tissue. It is noncellular and nonvascular and is called 'white of the eye'. It provides protection and maintains form of eyeball.
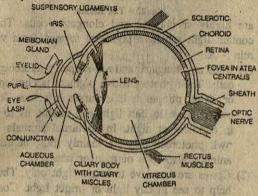
Fig. 23.2 V. S. Eye.

On the exposed or projecting 1/6th part of eyeball sclerotic forms a thin transparent covering, called **cornea**. Limbus is the circular line of union between cornea and sclera and is also called **sclero-corneal junction**. Cornea is covered by a thin transparent but vascular **conjunctiva**, formed of modified epidermis. It is continuous with the lining of eyelids.

2. **Choroid or Uvea** - This is the middle coat of eye. It is comparatively thin, soft and highly vascular. It is formed of connective tissue with pigment cells and some smooth muscles. It is adhered to sclera but separates a little before reaching the sclero-corneal junction and forms a pigmented curtain behind cornea. It is called **iris**. The colour of iris may be dark brown, black or blue depending on the pigment present in the choroid.
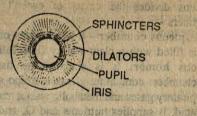
Fig. 23.3 Arrangements of muscles in iris

The iris is perforated by a rounded **pupil**. Iris contains intrinsic circular and radial smooth muscles. The contraction of circular muscles contracts the pupil and contraction of radial muscles dilates it.

Ciliary body - Along the peripheral margin of iris, the choroid forms a ring - like **ciliary body**. It bulges into the interior of eyeball as **ciliary processes**. Ciliary body is vascular and pigmented and is formed of a thick folded band containing smooth **ciliary muscles**. The ciliary muscles contain circular, radial and oblique fibres.
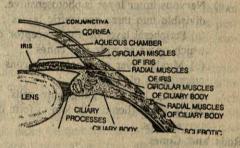
Fig. 23.4 Ciliary Body

Muscles of iris and ciliary muscles have rich autonomic supply with nerve fibres from both sympathetic and parasympathetic systems.

Thread-like **suspensory ligaments** extend from ciliary body to the biconvex lens.

Lens - It is an elastic structure, formed mainly of non-nucleated, transparent and elongated cells. It is enclosed in a transparent membrane - like capsule of elastic connective tissue.

System of ligaments called suspensory ligaments or zonal fibres and ciliary muscles control curvature of lens and thus its focal length. Several finger-like processes of ciliary body are attached to the equatorial line of lens and hold it firmly in its place by elastic fibres.

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Lens divides the cavity of eyeball into two chambers -

1. **Aqueous chamber** - It lies in front of lens and is filled with a clear watery fluid called **aqueous humor**. It is actually the tissue fluid chamber containing glucose, amino acids, respiratory gases and metabolic wastes and ascorbic acid. It supplies nutrients and O_2 and removes metabolic wastes from the neighbouring cells.

2. **Vitreous chamber** - It lies behind the lens and is much larger than aqueous chamber. It is filled with a viscous jelly-like substance called **vitreous humor**. It contains 99% water, some salts, some mucoproteins called **vitreen** and hyaluronic acid.

3. **Retina** (Neuro-sensory layer)- **Retina** is the innermost thin layer of eyeball. It lies against entire choroid. It is formed of two layers.

   (i) **Pigmented outer layer** is formed of single layer of cuboidal cells containing dark brown pigment.

   (ii) **Nervous inner layer** is photosensitive. It is divisible into three concentric layers :

   (a) Peripheral layer of **photoreceptor cells** which occur as **rods** and **cones**.

   (b) Middle layer of **bipolar neurons** and other types of neurons.

   (c) Inner layer of **ganglionic cells**. The axons of ganglionic cells join to form optic nerve fibres.

Rods and Cones

Photoreceptor cells of vertebrate eye are called rods and cones because of their appearance. These
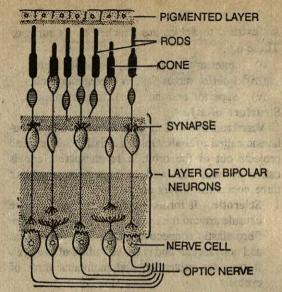
Fig. 23.4 T.S. Retina.

are highly specialized and elongated cells. These contain light sensitive pigments formed from vitamin - A.

(1) **Rods** are elongated and rod-shaped photoreceptor cells. Their photosensitive pigment is **rhodopsin** or **visual purple** as it is purple in colour. Rods are sensitive to dim light and enable us to see in darkness at night. In nocturnal animals like owl, photoreceptors are mainly rods, in other animals also rods outnumber cones.

(2) **Cones** are sensitive to bright light only. These help to see in day light or bright light. Cones are also associated with perception of colours. Their photosensitive pigment is violet colour - **iodopsin**.

Table 23.1: Summary of coats of eyeball

S.No.	Eye coat	Divisions	Characteristics	Functions
1.	Sclerotic (Sclera) (outer coat)	Posterior part – Sclera proper Anterior part – cornea	White, opaque fibrous coat Transparent	Protection Protection
2.	Choroid (middle coat)	(i) Choroid proper – posterior part	Pigmented and vascular	(i) Nourishes cells of retina (ii) Absorbs extra light. (iii) Prevents blurring of image.
		(ii) Ciliary body	Disc - shaped	(i) Provides attachment to suspensory ligaments and iris. (ii) Secretes aquous humor. Suspends the lens.
		(iii) Suspensory ligament (iv) Iris	Pigmented diaphragm	Regulates the size of pupil and the amount of light entering the eye.
3.	Retina (Inner coat)	(i) Pigmented layer (ii) Nervous layer	Formed of rods and cones; bipolar neurons and ganglionic layer.	Rods function in dim-light and form black and white image Cones function in bright light and differentiate colours.

Distribution of Rods and Cones

1. Rods are present at the periphery of retina only.
2. Cones are more abundant on the rear wall in the area of fovea. Between these two regions, rods and cones are found intermixed.
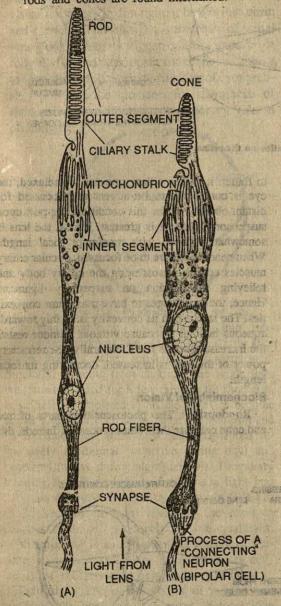
Fig. 23.5 Diagram of a rod and a cone.

Area Centralis and Fovea

Centre of retina is the **area centralis**. It lies upon the optical axis. It is the region of highest visual acuity, because of highest density of cones – some 150,000/mm² in man and as many as 1,000,000/mm² in some birds of prey.

Fovea centralis is a depression in the centre of area centralis. Here retina is thinnest and lacks blood vessels. Fovea is regarded to be extremely sensitive to light and associated with the formation of magnified image.

Blind Spot

At the spot where optic nerve and blood vessels exit the retina, the rods and cones are absent. It is unable to receive light rays and is called **blind spot**.

Working of the Eyes

Stimulation of rods and cones (= photoreceptor cells) produces sensations of light variations, and colours, form and motion of objects. For a proper perception of objects and patterns in detail, light rays that are reflected by the objects and enter into the eyes should fall upon the retina in perfect focus.

The conjuctiva, cornea and aqueous humour are convex towards outer side, while both sides of the lens are spherical or convex. The central point of the lens is called **optical centre**. All light rays, whether straight along the central (= principal) axis of the lens, or diagonal along secondary axes, but intersect the principal axis at optical centre, remain straight. Conversely, all light rays that do not pass through the optical centre are refracted by all refractory media of the eye including the lens.

"Light rays coming from objects at a distance of 50 cms. or more may be considered as parallel as far as human eye is concerned. When such parallel rays pass through a biconvex lens, all except those on principal axis are first refracted and, then, meet at a point upon principal axis called **principal focus**. The distance upon the between the principal facus and the optical centre is called **focal distance** of the lens, which varies with curvature and refractive properties of the lens. In a perfect focus, a small inverted image of the distant object appears behind the focal point upon retina.

Light rays coming from objects nearer than 50 cms. are oblique rather than parallel. Such rays, except those passing through the optical centre, are refracted and made to meet at the principal focus upon the principal axis, forming a small inverted image beyond the focus point. The image distance of a near object will obviously vary with the distance of the object from the lens.

Inverted image – The image formed is always "inverted". When sensory impulses of this image are carried to the brain by fibres of optic nerve, the nerve centres of sight, located in thalamus and cerebral cortex, analyse and co-ordinate

(1) LIGHT FROM THIS POINT OF OBJECT IS REFLECTED IN ALL DIRECTIONS...

(2) ...BUT ONLY THE LIGHT RAYS WITHIN THIS CONE WILL ENTER EYE

(3) THESE LIGHT RAYS ARE BENT AT THE CORNEA AND LENS...

(4) ...AND BROUGHT TO A FOCUS ON THE RETINA SO THAT EACH POINT OF LIGHT ON THE OBJECT FORMS A POINT OF LIGHT ON THE RETINA, SO MAKING AN IMAGE (I)

lens

CORNEA   AQUEOUS HUMOUR

(B) MOST REFRACTION TAKES PLACE BETWEEN THE AIR AND THE CORNEA

Fig. 23.6 Image formation on the retina.

these impulses so that the animal becomes aware of the normal erect pattern of the object, *i.e.* it actually "sees" the object. Thus, it is the brain, and not the eyes, that is responsible for 'seeing'.

Accommodation- This is the adjustment of eye to enable it to focus on objects at various distances.

Mammalian eyes have remarkable power of accommodation, not by moving the lens towards the cornea or retina, but by changing the convexy of the lens. Alternating the shape of the lens changes its focal distance, so that images of objects at variable distances can be brought to focus upon the retina.

The ciliary body and the suspensory ligament are specifically concerned with suspension of the lens and changing its shape for accomodation. Since the lens is somewhat elastic, any pull on it would tend

to flatten it. When ciliary muscles are relaxed, the eye is considered to be at rest and focussed for distant objects. Under this condition, the pull upon suspensory ligament is greatest. Hence, the lens is somewhat flattened with maximum focal length. When near objects are to be focussed, circular ciliary muscles contract, broadening the ciliary body and relieving the tension on suspensory ligament. Hence, the lens bulges to have maximum convexities. The increase in its convexity is mainly towards aqueous humour , because vitreous humour resists the increase towards itself. Naturally, the refractory power of the lens is increased, decreasing its focal length.

Biochemistry of Vision

Rhodopsin : The photosensitive parts of rod and cone cells are their outer processes. In rods, this

SUSPENSORY LIGAMENT TIGHT

JUMOURS PRESSING OUT ON SCLERA

LENS GETS THICKER

CILIARY MUSCLE CONTRACTS

LENS PULLED THIN

LIGHT FROM DISTANT OBJECT

LIGHT FOCUSED ON RETINA

(A) ACCOMMODATED FOR DISTANT OBJECT

LIGHT FROM NEARBY OBJECT

TENSION IN SUSPENSORY LIGAMENT RELAXED

(B) ACCOMMODATED FOR NEAR OBJECT
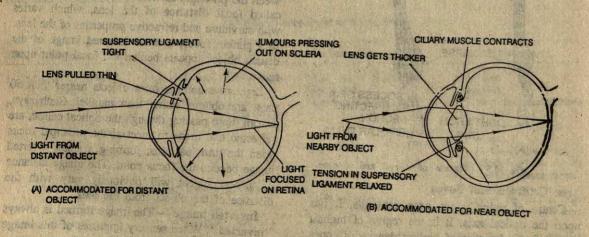
Fig. 23.7 Accomodation.

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part contains a shining pigment called **rhodopsin, or visual purple.** Like hemoglobin, rhodopsin is a compound of a protein (= **opsin or scotopsin**) and a pigment (= retinine). In bright light it disappears, fades away, or is reduced to a state unfit for visual sensation. In dim light, it breaks into opsin and retinene. This changes is the basis of visual sensations, because it triggers sensory impulses in rod cells. In darkness, opsin and retine recombine to form rhodopsin. Periodic blinking of eyes probably provides the moments for resynthesis of rhodopsin, in addition to its important role in cleaning the eyes.
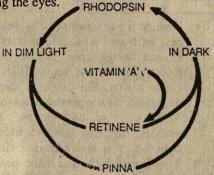
Fig. 23.8 **Rhodopsin cycle in rod cells.**

In going suddenly from bright light into darkness or semidarkness, we can see things only after a few minutes, when rhodopsin has reappeared. Similarly, in going from darkness into bright light we remain blinded for a few minutes till rhodopsin is sufficiently depleted to enable cones to become active visual cells. Disappearance of rhodopsin and its formation are, thus, important adaptations respectively in diurnal (= active during day) and nocturnal (active during night) animals. Temporary blinding in going suddenly from bright light into darkness or vice-versa is also due to the time (10 to 30 seconds in man) taken by the pupil to constrict or dilate respectively in these conditions.

Vitamin 'A' is an important constituent of retinene. Vitamin A deficiency naturally causes deficiency of rhodopsin, inducing night blindness.

Iodopsin : The outer process of a cone cell contains a different, voilet-coloured photosensitive pigment, named **iodospin** or **visual violet.** This pigment is sensitive to bright light and colours. Its biochemistry is not so well known as that of rhodopsin. Most scientists, however, hold the opinion that cones are of three varieties for three basic colours *viz.*, red, green and blue. Blending of these

colours in various combinations and grades enables the animals to have vision for various other colours such as white, orange, yellow, violet etc.

Choroid is said to prevent light rays from entering the eyeball from any direction other than that of the pupil. It absorbs the light which might filter out through retina, preventing a reverse reflection of the light. In many nocturnal vertebrates, however, the layer of choroid, next to retina, is specially modified to reflect back the light that falls upon it after filtering through retina, giving the eyes a sharp greenish "**glare or shine**" noticeable in the dark. In deep sea elasmobranch fishes and many mammals, this layer of choroid, called **tapetum,** contains light-reflecting crystals of a substance called **guanin.** It is, therefore, called **tapetum lucidum.** In marsupials, hoofed mammals, elephants and whales, the tapetum is a layer of connective tissue packed with glistening white tendon-type of fibres, and called **tapetum fibrosum.** Carnivore mammals, seals and lower primates possess a **tapetum cellulosum** composed of several layers of cells which are laden with crystals of an organic substance that does not seem to be related to guanin.

Significance of the 'glare' provided to the eyes by tapetum is uncertain. It may be a mechanism of aggression, or it is to increase the stimulation of retinal receptor cells.

Common Optical Defects

(1) Hypermetropia and myopia : The most common eye defects are **far-sightedness (= hypermetropia)** and **nearsightedness (== myopia).** Normal anteroposterior diameter of our eyeball is about 17.5 mm at birth and 20 to 21 mm. at puberty. All light rays entering into a normal eye converge, after refraction, at a proper focal point and then fall upon the retina, forming a normal image. We can clearly see objects from a distance of about 10 to 50 cms. with such normal eyes. An eyeball shorter in antero-posterior diameter is **hypermetropic.** It can clearly see only distant objects. Light rays from near objects fall, after refraction, upon the retina of such an eye before these converge, *i.e.*, the focal point lies behind the retina. Hence, only indistinct images of near objects form in such eyes. This condition also results from loss of elasticity of the lens with increasing age in man. **To see near objects clearly, hypermetropic patients have to use biconvex lenses. Conversely, the antero-poste-**

rior diameter of a **myopic** eyeball is somewhat longer than normal. Hence, the distance between the retina and focal point increases in case of distinct objects, so that only an indistinct image of such objects is formed. Sight for near objects is, however, clear. **Myopic patients, therefore have to use concave lenses.**

(B) NEARSIGHTED EYE

(C) FARSIGHTED EYE

(D) ASTIGMATIC EYE

x, SHARP   y, BLURRED IMAGE z, CORRECTION
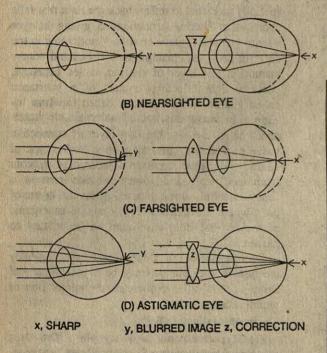
Fig. 23.9   Common abnormalities that cause defects in vision.

(2) Glaucoma : As mentioned before, the aqueous humour is like a tissue fluid. Fluid is continually added to it from arterial capillaries and reabsorbed by venous capillaries of ciliary body. Any interference with its reabsorption increases intraocular pressure, a condition known as **glaucoma.** It causes stretching of the wall of eyeball. The wall, therefore, bulges and becomes "cupped" in its weakest part which is its region traversed by optic nerve. The blood vessels connected with the eyeball also enter into or leave the ball at this point. Injury to these due to 'cupping' causes blindness in due course. An operation to drain excess quantity of aqueous humor is required to resort normal condition, but this is effective only if done before 'cupping'.

(3) Astigmatism : Irregularities in the shape of cornea are responsible for imperfect or indistinct image. This condition is **astigmatism.**

(4) Strabismus : If some extraocular muscle is, or becomes longer or shorter than normal, the eyeball remains somewhat bent on to a side in its eye orbit. This is called **strasbismus.**

(5) Cataract : In old age, the flexibility of the lens declines, so that the lens becomes less convex on both sides. Simultaneously, it may become somewhat opaque, acquire an amber colour, and increase in its density. This condition is known as **'cataract'.** It hampers normal vision.

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1. Human eye is sensitive to wavelengths ranging from 380 to 760 nanometer.
2. Human beings, apes, monkeys, birds, lizards, turtles and some fishes have colour vision. But domestic mammals and sharks do not possess colour vision.
3. Visible range of spectrum varies among animals. Bees can perceive ultraviolet light which is invisible to man.
4. In nocturnal birds and mammals retina has rods or mainly rods, that enable them to see in darkness.
5. Diurnal animals have mostly cones. They can perceive colour.
6. Vitamin A deficiency causes night blindness because pigment **rhodopsin** which is essential for vision in dim light is synthesized from Vitamin A.

EARS

(Stato-acousting Organs)

The **ear** (organ of hearing) in mammals is divided into the external, middle and internal ear respectively.

External Ear

The external ear or **pinna** is a skin flap, supported by cartilage. It is designed to catch and concentrate the sound waves. It surrounds an aperture which leads into auditory canal or the **external auditory meatus**. The external auditory meatus terminates at the **ear drum or tympanum** or **tympanic membrane**. It is formed of circular and radial collagenous fibres and its centre bears a depression, the **umbo**. Its outer surface is covered with skin but the inner with the mucous membrane. The tympanic membrane vibrates to sound waves
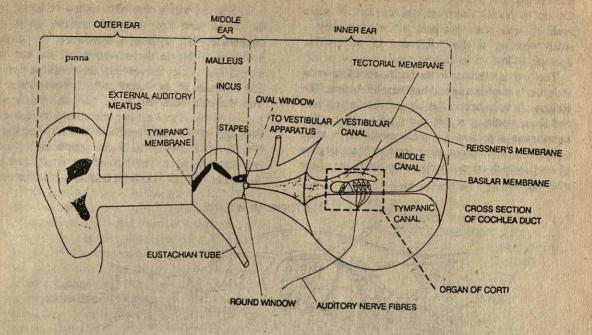
Fig. 23.10 Ear of man.

and transmits them through ear ossicles to the internal ear.

Middle Ear

The middle ear or the tympanic cavity is a small chamber which encloses three bony ear ossicles-malleus (hammer-shaped), incus (anvil-shaped) and stapes (stirrup-shaped). The outer end of stapes is attached to the margins of fenestra ovalis or fenestra vestibuli. Therefore, through the ear ossicles the tympanic membrane is connected with the internal ear. These transmit vibrations to the internal ear.

Internal Ear

The semicircular canals, utriculus and sacculus parts of internal ear are concerned with the maintenance of balance and play no part in hearing. The cochlea part is associated with hearing. It is very much like a conch-shell. It is a bony tube about 23-30 mm. in length. It arises from sacculus and is spirally wounded around a cone of bone, which is known as the central pillar or mediolus. The cochlear nerve passes through the central pillar. A spiral osseous lamina arises from the central pillar. To the free end of spiral lamina are attached two

membranes, which extend to the wall of canal and divide its cavity into three chambers - **scala vestibuli, scala media** and **tympani.**

The scala vestibuli and scala tympani are filled with perilymph, while the scala media contains,
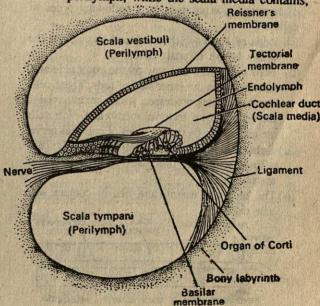
Fig. 23.11 T.S. Cochlea.

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endolymph. The scala media does not extend upon the tip of helix. Therefore, the cavities of scala vestibuli and scala tympani communicate by a small opening at the distal end of helix. This opening is known as **helicotreme.**

The two membranes in the cochlea are known as **Reissner's membrane** and **basilar membrane.** The **Reissner's membrane** lies between scala vestibuli and scala media. It is thin and simple. The **basilar membrane** separates the scala media from scala tympani. It is complex structure and bears **organs of corti**, which are connected with the fibres of the auditory nerve.

Mechanism of Hearing

The sound vibrations from air are collected by the pinna and are funneled on the tympanic membrane. The tympanic membrane is pushed inward resulting in the movement of the ear ossicles. The stapes moves into the **fenestra ovalis** and displaces the perilymph, which moves inwards into the cala vestibuli. From here the perilymph passes across the Reissner membrane to the endolymph of the scala media of the cochlear duct. This in turn displaces the basilar membrane towards the scala tympani. The basilar membrane and its associated structures exhibit undulating movements
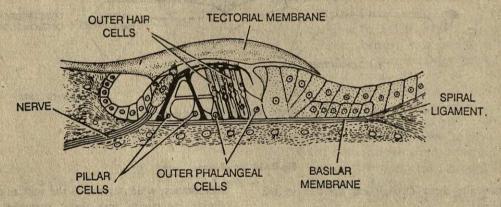
Fig 23.12 Human Ear – Organ of Corti

Fig. 23.14 Position of tectorial membrane in relation to organ of Corti.

Organ of corti - The organ of corti is the organ of hearing. It is composed of following types of cells :

(i) **Rods of croti** which are found throughout the whole length of scala media.

(ii) **Hair cells** from one row on the outer side and three rows on the inner side of rods. These cells bear bristle-liek processes, which are attached to the underside of tectorial membrane. Hair cells are innervated by the branches of cochlear nerve.

(iii) **Subtentacular cells of Deiter** (Deiter's cells), whose peripheral processes form a **reticular membrane.**

(iv) The **tectorial membrane** lies in contact with hair cells.

Fig. 23.13 Relationship of scala vestibuli and tympani.

which cause the hair cells to touch the tectorial membrane. These touch stimuli set up impulses in the nerve fibres of the hair cells. These nerve fibres finally join form the cochlear branch of the auditory nerve. The sound vibrations of a given frequency cause movements of the basilar membrane of equal frequency.

It is believed that when **hair cells** touch the tectorial membrane, these release a chemical, the **acetylcholine**, which causes the generation of action potential and initiates the nerve impulse. Three different theories have been put forward regarding the interpretation of sound impulses :

1. **Telephone theory** - According to this theory the organs of corti act as a unit, like a diaphragm in the telephone. The sound waves are received by the hair cells of the basilar membrane and are transmitted by the cochlear nerves to the brain without any change.

2. **Resonance theory** - According to resonance theory the basilar membrane is composed of

thousands of fine fibres, strung along like the string of harp. The short and tightly stretched strings lie towards the base, while the long and loosely-stretched strings towards the apex of the cochlea. A particular sound sets up vibrations of a specific frequency in the air. The vibrations of the same frequency are set in the ear drum, ear ossicles and then in perilymph and basilar membrane.

3. **Microphone theory** - **Weber** and **Bray** suggested concept of **microphonic impulse**. The organs of corti are responsible for the conversion of mechanical energy into electrical energy. The perilymph has a positive charge of about 70 mV and endolymph of 80 mV. But the cell elements of organs of Corti and vascular tissue on scala media bear negative charge of 15 mV. This is known as **resting potential**. The vibrations in the basilar membrane change the potential difference of the hair cells. This changer potential is known as **receptor potential**. The asymmetrical sound waves produce additional response bending hairs of hair cells. This is known as **summation potential**. Both the **receptor** and **summation potentials** transmit the electrical waves to the auditory nerve, which carries them to the brain.

Recognition of Intensity and Pitch

The intensity of sound is determined by the amplitude of the sound waves impinging upon the tympanic membrane. This determines the amplitude with which the basilar membrane vibrates. Loud sounds produce sound waves of large amplitude and bring about greater displacement of the basilar membrane. Therefore, loud sounds produce impulses of higher frequency in the auditory nerve fibres.

The pitch of sound is set by the frequency of the sound waves i.e. the **wavelength**. High tone is produced by the sound wave of high frequency (with short wavelength) and vice versa. The pitch of a sound wave, therefore, determines the frequency at which the basilar membrane vibrates. The sensory cells in different regions of the cochlea respond to different frequencies. The sensory cells towards the apex respond to low tones while those towards the base respond to high tones. This actually depends upon the stiffness of basilar membrane. The stiffness gradually decreases from base to the apex of the cochlea.

OLGACTORY ORGANS
(Olfactory Receptors)

Olfaction (= Sense of Smell) is detection of a substance as an odour. It is found in all vertebrates but is relatively less developed in humans than in some other mammals.

Organs of Olfaction

Receptors for olfaction lie in the mucosa of upper part of nasal chamber. Nasal mucosa in this region is called **Schneiderian membrane** or **olfactory epithelium**. It lines the surface of only a small area about 5 cm^2 near nasal septum and is in the form of a **pseudostratified epithelium**. It is formed of three types of cells:
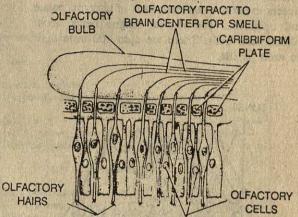
Fig. 23.15 Diagram showing olfactory organ and its sensory receptors.

1. **Olfactory receptor cells** are **chemoreceptors** because these are sensitive to chemical stimuli. Their basal ends are connected with the dendrites of sensory neurons.
2. **Supporting cells** and
3. **Basal cells.**

Function

Olfactory receptors are very sensitive to those chemicals or substances that are air borne (volatile) and soluble in both water and lipids.

Odour bearing air when passes through the nasal passage, the scent molecules are trapped by the moisture on the surface of olfactory receptor cells and odour is perceived. The stimuli are carried by olfactory nerve to the brain.

Because of the shape of nasal passages, most of the air normally bypasses the olfactory receptors and feeble odour remains undetected. Sniffing increases efficiency of detection of odour.

A continuous inhalation of a particular smell gradually weakens the smell sensation for that particular smell. Finally, it completely disappears. These **olfactory adaptations** are because of changes in the receptors and olfactory centres of the brain.

Sense of smell is highly developed in dogs that is why dogs can distinguish odours from different persons and can track them.

ORGANS OF TASTE
(Gustatory Receptors)

Receptors for taste are grouped to form **taste - buds.** The taste buds are located on the peg-like **papillae** on the surface of tongue, but some are present in the mucous membrane of pharynx, palate and epiglottis. The human tongue bears about 10,000 taste buds. There are upto 100 taste buds on each papilla.

The basal ends of receptor cells are connected with the nerve fibres of sensory neurons and their free ends are produced into hair like **sensory processes** which project out of the taste bud-through a pore.

Function - Taste receptors are **chemoreceptors.**
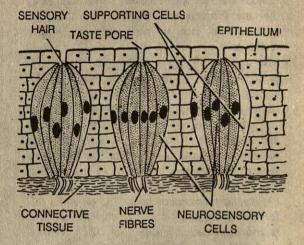
Fig.23. 17 V.S. Taste bud.

These detect substances that are soluble in water. These can perceive different tastes.

Distribution of taste buds. Taste buds for sweat, sour, salt, bitter are located at specific regions on the tongue.

1. **Receptors for sweat** substances are located at the front of tongue.
2. **Salt receptors** are present on tip and sides.
3. **Receptors bitter** taste are located at the rear.
4. **Sour receptors** are at the back and rides.

Fig. 23.16 Human Tongue to show papillae.
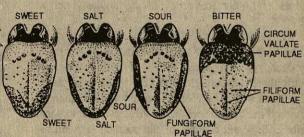
Fig. 23.18 Showing areas of human tongue for different tastes.

A **taste bud** is an ovoid body. It consists of **taste receptor cells** surrounded by supporting cells.

1. Describe detailed structure of retina. Give functions of rods and cones and their location.
2. What causes night blindness and why?
3. What is stercoscopic and binocular vision?
4. What do you understand by accomodation in reference to vertebrate eye? Describe mechanism of accomotion in human eye.
5. What is tapetum? What is the function in mammalian eye.
6. Why owls can see at night in dim light but not we?
7. Name any mammals who cannot perceive colour.
8. Comment on the biochemistry of vision.
9. Describe structure of a taste bud.
10. Name the bones present in the middle ear of mammal and help in receiving auditory stinuli.
11. Describe structure and function of internal ear of mammal.
12. Describe cochlear apparatus and how it perceive Sound waves.
13. Differentiate between.
    (i)   Rods and cones
    (ii) Exteroceptors and visceroreceptors.
    (iii) Proprioceptors and visceroceptors.
    (iv) Middle ear and internal ear.
    (v)   Cristae and maculae.
14. Why Vit. A deficiency causes night blindness.
15. What is the name of hearing sene organ? And of the equilibrium sense organs.
16. Discuss roles of organs of corti.
17. Explain briefly the mechanism for accommodation for near vision.
18. Define refraction. Name the refractor medium of eye.
19. Name the receptors for colour vision and for vision in dim light and bright light.
20. Why do we soon stop smelling the perfume on our dress while persons approaching you still perceive its smell?
21. The following functions of
    (i)   gustatory cells   (ii) Fovea.   (iii) Blind spot
    (iv) Ciliary muscles   (v)   Suspensory ligament   (vi) Rods
    (vii) Cones   (viii) Ear ossicles
22. Define the following terms -
    (i)   Receptors   (ii) Accommodation.
    (iii) Photoreceptors   (iv)
23. Describe anatomical abnormality that produce each of the following visuaolp defects :
    (i) Myopia   (ii) Hypermetropia   (iii) Atigmatism.
24 What are otoliths and what are their role in maintaining equilibrium.
25. Select the most appropriate answer in column B for each description in column A.

Column A	Column B
1. Light - sensitive part of human eye	a. cones
2. Regulates size of pupil	b. Iris
3. Perception of colour	c. Fovea.
4. Region of keenest vision	d. Retina.

26. Fill In the Blanks
    (i)   A sense organ consists of one or more _____ cells.
    (ii) Exteroceptors are sense organs that _____.
    (iii) The _____ form image in black and white while _____ help in colour vision.
    (iv) Chemoreceptors in mammals includes receptors for _____ and _____.
    (v)   Each semicircular canal of internal ear is filled with a fluid called _____.
    (vi) The photosensitive pigment in vertebrate eyes is _____.
    (vii) The internal ear of vertebrates is formed of sacs and interconnected canals. It is known as _____.

Locomotion

Movement is one of the important characteristics of all living beings. In multicellular organisms, movement takes place in two forms –

1. **Movement of body parts** in relation to body axis.
2. **Locomotion** displacement or progression of an organism from it place.

Movement of Body Parts

Movement of body parts represents -

1. Movement of fingers, limbs, head, trunk in relation to body axis to bring about postural changes. These movements help in maintaining equilibrium.
2. Movement of jaws, tongue, snout etc. for ingestion of food.
3. Movement of eyeball, eyelids.

Locomotion

Locomotion is the basic character of animals. It includes act of walking, running, crawling swimming, hopping, gliding or flying in the air.

Purpose of Locomotion - Locomotion is essential as it serves following purposes -

1. It enables organism to move as a whole from one place to another.
2. It enables animals to move away from enemy or away from undesirable places.
3. It helps in searching and procuring food and water.
4. It enables the animal to find its mate or partner for sexual reproduction.
5. It enables them to migrate to more favourable locations of food, shelter and suitable places of egg laying etc.

MUSCULO-SKELETAL SYSTEM

With few exceptions locomotion is brought about by the contraction of **muscles** against some kind of **skeleton**. The **muscles-skeletal system** is the basis of locomotion and movement. In vertebrates locomotion depends on the association of **skeletal muscles** or striated muscles with the **skeletal system** formed of bone or cartilage. These muscles are called **voluntary muscles** as their activity is under the will of animal and the skeleton is known as **endoskeleton** as it is found internal to the muscles.

HUMAN SKELETON

Human skeleton is formed of bone and cartilage. It is formed of 206 bones. These are of various sizes ranging from the tiny bony ossicle of the middle ear to the long thigh bone or femur.
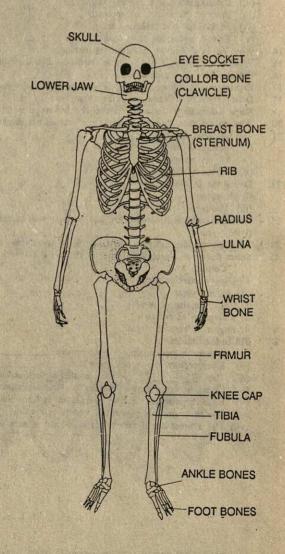
Fig. 24.1   Human skeleton.

Function of Endoskeleton

(1) It functions as a well-organised framework, and imparts definite shape to the body.

(2) **Support** - it provides support to whole body, including the limbs, so that the body does not collapse or become shapeless.

(3) **Movement** - The striped muscles lie under the skin and in the limbs, surrounding the skeletal framework. It provides attachment to these muscles. When muscles contract, the skeletal elements move at their joints like levers moving at fulcra. These movements of skeletal elements are responsible for various movements of the body and its parts.

(4) **Protection** - It protects all internal organs from external pressures, injuries and other hazards.

(5) It houses and protects the brain and spinal cord.

(6) **Breathing** - It helps in breathing.

(7) **Hearing** - Certain bones, located in the ears, help in hearing

(8) **Haemopoiesis** - The long bones of limbs are hollow and contain a soft tissue, the **bone marrow**, in their cavities. The bone marrow is mostly **haemopoietic**, *i.e.* it produces blood corpuscles.

(9) **Reservoir** - The bulk of body's calcium remains in the bones. Continuous dissolution and reformation of bones throughout life is a **homoeostatic mechanism** to regulate calcium metabolism in vertebrate body.

Divisions of Skeleton

Study of vertebrate endoskeleton is called **osteology**. For convenience of study, the whole endoskeleton is divided into two main parts –

I. Axial Skeleton - It is formed of bones that constitute the upright axis of the body. It is differentiated into following parts –

1. **Skull** - It is skeleton of head and is formed of **28 bones**. It can be divided into following regions:

   (i) *Cranium* or brain - box, encloses the brain and is formed of 8 bones namely frontal, parietal (2), temporal (2), Occipital, sphenoid and ethmoid.

   (ii) *Facial bones* - These form facial part of skull and are 14 in number. These include nasals (2), maxillary (2), Squamosals or malars (2), mandible lacrymal (2), palatine (2), turbinals (2) and vomer.

   (iii) **Ear bones** - These are 3 pairs or six. Malleus (2), incus (2) stapes (2).

2. **Hyoid** - It supports tongue.

3. **Vertebral column** - It forms axis of the body and can be compared to **cantilever bridge**.
   It supports the body like a beam; protects the viscera; houses and protects spinal cord. It provides leverage and support to girdles and thus assist in locomotion. To provide axial flexibility, it is formed of small ring shaped bony pieces, called vertebrae. The total number of vertebrae in man is **26**. Vertebral column is differentiated into following regions -

   (i) **Cervical vertebrae** - 7 in number and present in neck region.

   (ii) **Thoracic vertebrae** - 12 in number. Along with sternum and ribs these form **thoracic basket** and enclose the most vital body organs (*i.e.* lungs and heart) and provide articulation to pectoral girdle.

   (iii) **Lumbar vertebrae** - 5 in number; provide articulation to pelvic girdle.

   (iv) **Sacral vertebrae** - are actually five but in adult these are fused to form a single bone.

   (v) **Caudal vertebra or coccyx** - It is a small bony piece showing rudimentary tail vertebra.

4. **Sternum and Ribs** - sternum forms the floor of thoracic basket and supports anterior part of chest. It consists of three parts - *manubrium*, body and xiphoid process.
   Associated with sternum are 12 pairs of ribs.

II. Appendicular Skeleton - It is formed of bones appended to axial skeleton *i.e.* bones of upper and lower limbs. It is formed of 126 bones.

1. **Bones of upper extremities** - 64 bones

   A. **Pectoral girdle** - It provides articulation to the bones of forelimb and is formed of **Scapula** (2) and **clavicle** (2).

   B. **Bones of forelimbs** (60) - These are humerus (2), radius (2), ulna (2), carpals (16), metacarpals (10) and phalanges (28).

2. **Bones of lower extremities** - 62 bones

   A. **Pelvic girdle** - two halves of pelvic girdle. It provides articulation with bones of hind limb.

   B. **Bones of hindlimb** - Femur (2), patella (2), tibia (2), fibula (2), tarsals (14), metatarsals

(10) and phalanges (28).

JOINTS OF ENDOSKELETON

Bones are articulated with one another by **movable** or **immovable joints**. In movable parts of body, these joints act as **fulcra** on which the bones move as **levers** to bring about the desired movements. All joints may be classified into two main categories - **movable joints (= diarthroses)** and **immovable joints (= synarthroses)**.

Diarthroses or Movable Joints

These are classified into two main catagories - **perfect and imperfect**.

normal positions after movement. That is why, bones articulated by perfect joints have sufficient freedom of movement.

A sudden voilent twist or pull may cause excessive stretching of ligaments. This is called **sprain**. Sometimes the ligaments even get torn and articulating bones displaced. This is called **dislocation**.

The perfect joints are of the following types :

(1) **Ball-and-socket joints (= enarthroses)** : In such a joint, the ball-like end, or 'head', of one bone fits into a socket or concavity of the other

A

PELVIC GIRDLE
HEAD OF FEMUR (BALL)
ACETABULUM (SOCKET)
ARTICULAR CARTILLAGE
SYNOVIAL CAVITY FILLED WITH SYNOVIAL FLUID
SPONGY BONE
SYNOVIAL MEMBRANE
FIBROUS CAPSULE
BONE MARROW
HARD BONE

B

SYNOVIAL MEMBRANE
FIBROUS CAPSULE
SYNOVIAL CAVITY FILLED WITH SYNOVIAL FLUID
SPONGY BONE
BONE MARROW
HARD BONE
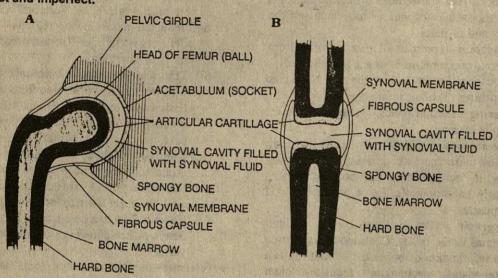
Fig. 24.2   Structure of a perfect joint

The perfect joints

In perfect joints the ends of articulating bones are covered with a thin cap of hyaline **articular cartilage**. The entire joint is enclosed within a tough **synovial capsule**. It is continuation of periosteum of both bones. The wall of the capsule is composed of an outer dense **fibrous layer** and a less dense, more cellular inner **synovial layer**. The cavity of the capsule is the space between the articulating bones. It is called **synovial cavity** and is filled with a sticky and lubricating **synovial fluid** (= synovia), secreted by the synovial membrane.

Perfect joint permits considerable movement of articulating bones without friction. Such joints are further reinforced by strong and elastic ligaments outside the synovial capsule. Their ligaments help in bringing the articulating bones back to their

(Fig. 24.3). The bone with the ball-like end can be freely rotated around at the joint. **Example** - Articulation of humerus bones in the glenoid cavities of pectoral girdle at shoulders and that of femur bones in the acetabula of pelvic girdle in pelvis are joints.

(2) **The hinge joints (= ginglymi)** : In this, a protruberance (normally a condyle) at the end of one bone fits into a corresponding depression of the other in such a manner that the bone with protruberance can be swung, like a door on its hinges, only in one direction. **Example** - knee and **elbow** joints and between the plalanges of digits.

(3) **Pivotal or rotary joints (=rotatoria)** : In such a joint, one of the bones is fixed and bears a peg-like projection or the **pivot**. The other, fitting over the pivot by a concavity freely rotates

ULNA
RADIUS

GLIDING JOINT
(FORE ARM AND WRIST)

SADDLE JOINT
(THUMB)
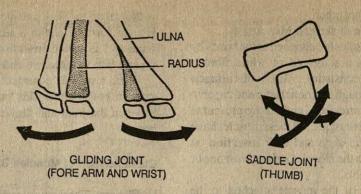
Fig. 24.3 Ball and socket (A) and hinge (B) joints.

INTERVENING
CARTILAGE

IMPERFECT JOINT
(PUBLIC SYMPHYSIS
OF RABBIT)

PIVOT JOINT
(SKULL AND 2ND
VERTEBRA OF
RABBIT)

IMMOVABLE JOINT
(SKULL BONE OF MAN)
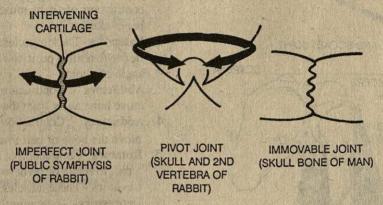
Fig. 24.4 Gliding, saddle, imperfect, pivotal and immovable joints.

around (Fig. 24.4). **Examples** - the first verte-bra (atlas), carrying the skull, rotates freely on the peg-like odontoid process of the second vertebra (axis).

(4) **The saddle joints :** These are like ball-and-socket joints, but both the ball and socket are poorly developed (Fig. 24.4). Hence, the ball-bearing bone can be rotated around, but not very efficiency. **Examples** - the metacarpal and carpal of thumb articulate by such a joint.

(5) **The gliding joints (=arthrodia) :** In these, the (Fig. 24.4) articulating bones can slide upon one another at the joint, but movement is naturally restricted. **Examples** - The joints be-tween the zygapophyses of successive verte-brae, and that between the radio-ulna and car-pals.

2. Imperfect joints

Ligaments and the synovial capsule are absent in such joints. Hence, the cartilage-tipped ends of the bones articulate directly with one another (Fig.

24.4). Such joints allow little movement of articu-lating bones. The pubic symphysis in the pelvic girdle of mammals is an example of such a joint.

Synarthroses or Immovable Joints

These include -

(i) **Sutures,** which are the lines of junction be-tween skull bones. Sutures are zig-zag lines (Fig. 24.4!) in which the serratted margins of articulating bones are interlocked.

(ii) **Gomphoses** in which a bony projection on one bone fits into a socket of the other as in the case of teeth in mandibles, premaxillary and maxil-lary bones.

(iii) **Shindylases** in which one bone fits into a slit in another as in the articulation of ethmoid bone with the vomer.

Ligaments

Movements are produced at joints of bones by the contractions of skeletal muscles inserted into the articulating bones. Flexible connective tissue bands called ligaments **stabilize** the joints by holding the

articulating bones together.

Tendons (Insertion of skeletal Muscles)

The skeletal muscles are attached to the bones by **tendons**. Tendons are formed of white fibrous connective tissue consisting entirely of **collagen fibres**. These are tough and nonelastic and capable of bearing sudden stresses. Tendons are present at the ends of skeletal muscles. All these muscles have their **origin** on one bone and their **insertion** on another bone. Thus the muscles span at least one or sometimes two joints.

The broad end of the muscle attached to the relatively fixed bone is called **origin**. It is usually without tendon. The opposite end of muscle which is in the form of tendon is attached to the movable bone and is called **insertion**. The thick part of muscle between the two ends is called **belly**.

When a muscle contracts its shortening puts a pull on both bones. This pull moves one of the bones at the joint and draws it towards the other bone.

Classification of Muscles Based on Function

1. **Flexors** - These muscles decrease the angle of a joint between anterior surfaces of bones *i.e.* contraction of these muscles brings the two bones closer.
2. **Extensors** - These muscles return the parts from flexon to normal position. *i.e.* these increase the angle of a joint.
3. **Abductors** - Contraction of these muscles move bone away from the middle line.
4. **Adductors** - Contraction of these muscles move the bone or part towards middle line.
5. **Rotators** - Contraction of these muscles cause a part to rotate or pivot on its axis.
6. **Levators** - These muscles raise a part.
7. **Depressors** - These muscles lower a part.
8. **Tensors** - These make a part tense or more rigid.
9. **Supinators** - Their contraction rotates the fore arm and turns the hand/palm upward.
10. **Pronators** - Turn the hand or palm downward.

Antagonistic Muscles

Skeletal muscles occur in **antagonistic pairs**. The muscles which contract to produce opposite movements at the same joint are called **antagonistic muscles**. Protractors are antagonistic to retractors, adductors to abductors, flexors to extensors.

Fig. 24.5 Diagram to show origin and insertion of skeletal muscles on the bones of upper arm.

How do Muscles Move Skeleton

When a muscle contracts to produce a movement, its antagonist relaxes to allow the movement to take place. For example **biceps muscle** is a flexor for the elbow joint and **triceps** is its antagonist, it acts as an extensor for the joint. During flexon at elbow, biceps contracts and triceps relaxes and during extension at the same joint triceps contracts
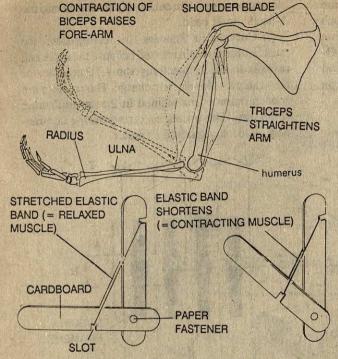
Fig. 24.6 The biceps and triceps muscles in the upper arm which move the arm at elbow joint.

Fig. 24.7 Diagram to illustrate the action of hind-limb in propelling the body forward.

and biceps relaxes.

Propulsion

In propelling the body forward the retractors and extensors play a major role. The long bones of hind limbs act as **lever**. The foot presses downwards and backwards against the ground. This produces an equal and opposite force which is transmitted along the length of limb against body. Its vertical component helps in lifting the body of the ground and horizontal component propels it forward.

Therefore, during propulsion **bones serve as levers and joints serve as fulcrums of these levers. Ultra-structure of Muscle Fibre.**

The cell membrane around each muscle fibre is known as **sarcolemma** and its cytoplasm as **sarcoplasm**. The numerous nuclei lie about the periphery of the fibre. Muscle cell contains a net work of **sarcoplasmic reticulum**, analogous to ER and large number of mitochondria. The sarcoplasm contains numerous longitudinal **myofibrils**, extending lengthwise.

Myofibril

Each myofibril is about 1 μm in diameter. It is differentiated into alternate light and dark coloured bands.

1. The **light bands** are nonrefractive under polarised light and are known as **isotropic bands** or **I-bands**. Each is bisected at its midpoint by a thin dark line, the **Z-band** or **Krause's membrane**. The portion of myofibrils between adjacent Z-bands is known as **sarcomere** and it represents the contractile unit. On both sides of Z-line, is a still darker—**N-line**.

2. The **dark bands** are doubly referactive and are known as **anisotropic bands** or **A-bands**. Each A-band is also bisected at the midpoint by a thin paler line. It is known as **Hensen's line** or **H-band**. A narrow dark line, **M-line** or **M-band** passes through the middle of H-band. Myosin filaments are thickened at M-bands.

PHYSIOLOGY OF MUSCLE CONTRACTION

filaments towards the centre of sarcomere into the A-band and H band.

(*i*) **Contractile Process** - In resting state, the muscle fibres remain relaxed because the **actin** and **myosin** do not form actomyosin-ATP complex as they carry similar electric charge. The calcium ion concentration is maintained in the **sarcoplasmic reticulum**. The events occurring during contraction can be summarised as under
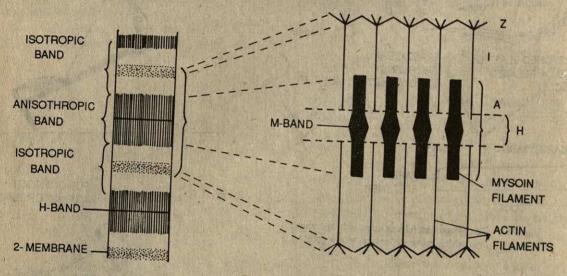
Fig. 24.8 Diagram showing structure of skeletal muscle.

Physical Change During Muscle Contraction

The process of muscle contraction is intimately associated with protein filaments of the myofibrils. The sarcomere is the unit of contractility and is represented by the region between successive Z-discs. During muscle contraction the thin actin filaments slide past among thick myosin filaments and result in shortening of sarcomere. The contraction of sarcomeres causes the muscle to shorten in length. During contraction I-bands shorten and Z-discs disappear, but the length of A-bands remains constant throughout the process.

Sliding Filament Theory of Muscle Contraction

This theory was put forward by HANSON and HUXLEY (1965). During muscle contraction, the thin actin filaments slide over the thick myosin

Step I - Depolarization of Sarcolemma : When a nerve impulse arrives at the junction of nerve ending in the muscle the sarcolemma of that muscle fibre is depolarized.

Step II - Release of Ca++ ions : The depolarization of sarcolemma is transmitted to the sarcoplasmic reticulum and causes release of Ca^{++} the sarcoplasmic reticulum.

Step III - Confirmational Changes in actin : The released Ca^{++} binds to TpC subunit of troponin. This produces conformational changes in tropomyosin and then in actin filament, preparing it to interact with myosin-ATP.

Step IV - Formation of actomyosin complex: The cross bridge of myosin binds to a globular subunit (G-actin) of the actin filament forming **actomyosin** complex in presence of ATP and Ca++ ions.

Step V - Break of actin-myosin bridge : ATP binds to myosin bridge, breaking the actin-
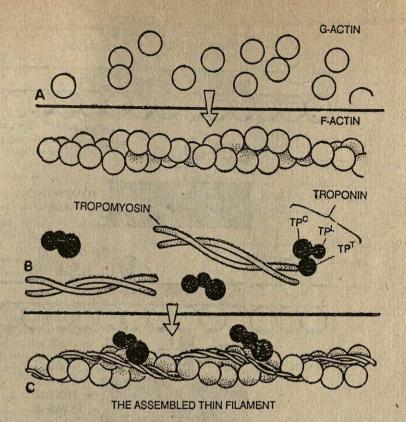
Fig. 24.9 Minute structure of actin filament .

myosin bridge to allow the movement of cross bridges leading to the sliding of thick and thin filaments past each other.

Summary of the events of Muscle Contraction

Depolarization of sarcolemma → Transfer of action potential to membranes of sarcoplasmic reticulum → Release of Ca⁺⁺ ions from sarcoplasmic reticulum → Binding of Ca⁺⁺ ions to TpC of troponin → Formation of cross bridges between actin-myosin ATP → Activation of myosin ATPase → Release of energy from ATP → Breaking of actin-myosin bond → Movement of cross bridges → Sliding of thick and thin filaments past each other.

Relaxation With the release of nervous excitation the sarcolemma develops electric potential and the sarcoplasmic reticulum restores Ca⁺⁺ ions from the sarcoplasm. With the decline of Ca⁺⁺ ions myosin-ATPase activity is inhibited, the cross bridges are broken and troponin releases Ca⁺⁺ ions leading to the restoration of resting state.

Summary of Events During Relaxation

Ca⁺⁺ pumped back into sarcoplasmic reticulum → Myosin-ATPase activity depressed → Cross bridges broken → Myosin and actin return back to resting stage → Tension (contraction)

disappears.

Chemical Events During Muscle contraction

1. A muscle is stimulated by **acetylcholine** released from the vesicles at the neuromuscular junction or motor end plate.
2. Acetylcholine evokes release of Ca⁺⁺ ions from the sarcoplasmic reticulum into the sarcoplasm.
3. In presence of ATP and Ca⁺⁺ ions, myosin binds to actin forming **actomyosin**.
4. Calcium ions activate enzyme **myosin - ATPase**, which breaks ATP into ADP and ~P. Energy, thus released is used for the contraction of muscle. Mg⁺⁺ ions are also essential for ATPase activity and for muscle contraction.

$$ATP \underset{Ca^{++},Mg^{++}}{\overset{ATPase}{\rightleftarrows}} ADP + P + E$$

5. Another high energy compound, **creatine phosphate (CP)** helps in immediate reconversion of ADP into ATP.

$$CP + ADP \rightleftarrows ATP + C$$
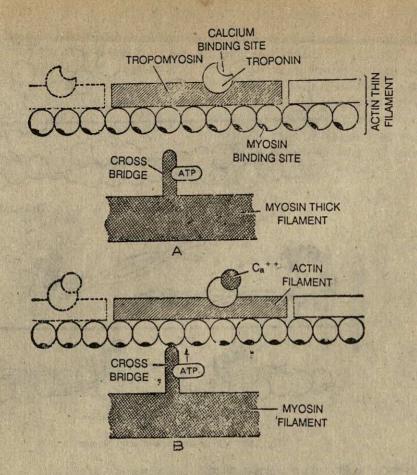
Fig. 24.10 Diagrammatic representation of action of cross bridges.

6. Glycogen in the muscle breaks down into lactic acid by glycolysis and liberates energy

$$\text{Glycogen} \rightleftarrows \text{Intermediates} \rightleftarrows \text{lactic acid} + \text{Energy}$$

7. Some of this energy is utilized in the reformatia of creatine phosphate (CP) and also for the conversion of some (4/5th) of the lactic acid back into glycogen.

8. The remaining 1/5th of lactic acid is oxidised into water and carbon-dioxide.

$$\text{Lactic acid} + O_2 \rightleftarrows CO_2 + H_2O + E$$

The energy released is utilized for the reformation of ATP.

Cori Cycle

The release of energy from muscle glycogen involves a number of steps. These are grouped together under **Cori Cycle**, described by CORI and CORI.

Muscle Fatigue

A muscle which has contracted many times, has exhausted its energy stores (ATP, CP and glycogen) and has accumulated lactic acid, is unable to contract and is said to be **fatigued**. Fatigue is caused due to accumulation of lactic acid. Muscle fatigues sooner after a **strenous** exercise than after mild exercise.

Excitation of Muscle

Each skeletal muscle is composed of many muscle fibres. The contraction of a muscle results from the contraction of its muscle fibres. Each muscle fibre is supplied by a nerve that propogates nerve impulses to the muscle fibre. Muscle fibre responds to the stimulus by contracting or shortening and relaxes in absence of stimulus.

The area of contact between a nerve and muscle

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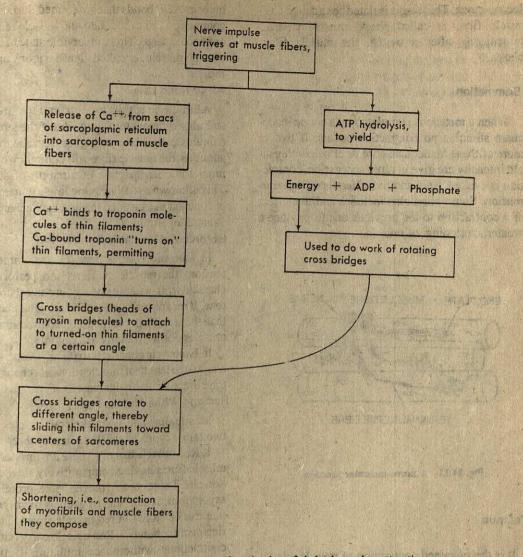
Fig. 24.11 Diagrammatic representation of mechanism of skeletal muscle contraction.
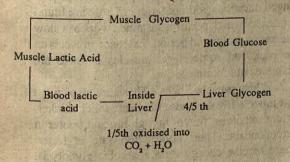
Fig. 24.12 Diagrammatic representation of cori cycle

fibre is known as **motor end plate or neuromuscular junction.**

Threshold Stimulus

For being stimulated the muscle fibre always requires a specific minimum intesity of the nerve impulse. Below this intensity the stimulus fails to evoke contraction. This is called **Threshold stimulus.** It differs from fibre to fibre even in the same muscle.

Single Muscle Twitch

A muscle fibre contracts only once on being stimulated by a single nerve impulse or by a single

electric shock. This single isolated contraction of muscle fibre is called **single muscle twitch**. Immediately after a twitch, the muscle fibre relaxes.

Summation

When a muscle is stimulated by a single inadequate stimulus no contraction occurs. If two or more of these inadequate stimuli of below threshold intensity are give in rapid succession, contraction is evoked. This additive effect is called **summation**. Summation also includes additive effect of a contraction to the previous one to produce a greater shortening of muscle.

END PLATE   MUSCLE FIBRE   NERVE

TERMINAL NERVE FIBRE
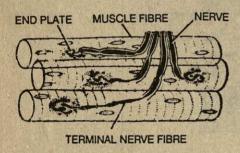
Fig. 24.13 A neuro-muscular junction.

Tetanus

It is the sustained contraction of muscle due to fusion of many twitches following each other in rapid succession due to repeated brief stimuli at such a frequency that each successive stimulus comes after the refractory period of preceeding one. As a result in **tetanus** the muscle remains in long contraction phase.

Rigor Mortis

ATP is essential during muscle contraction for dissociating actin and myosin and producing relaxation. After death, cells can not synthesize ATP. Due to fall in ATP concentration, the acto-myosin-ADP bonds that are formed during muscle contraction fail to separate and muscle remains in contracted stage. This irreversible state of contraction of muscle is called **death rigor'** or **'rigor mortis'**.

All Or None Law

A muscle fibre fails to contract if the strength of stimulus is below threshold. But if the strength of stimulus is equals to or higher than the threshold stimulus, the muscle fibre will contract with maximum force irrespective of strength of stimulus. This is known as **'all or none law'**. It means force of contraction cannot be increased by enhancing the strength of stimulus.

Isotonic and Isometric Contraction

In **Isotonic contraction** (G. *iso*, same-*tonus*, tension) the muscle shortens and performs mechanical work without undergoing any change in its tone. It means resistance offered by the load is less than the tension developed. *e.g.* contractions of leg muscles during walking are isotonic.

In **Isometric contraction** (G. *iso*, same + *metric* length) the length of muscles does not change but its tone is considerably increased.

Red and White Muscle Fibres

Mammalian and avian skeletal muscles contain two major types of striated muscle fibres -

1. Red muscle fibres - These are thinner, darker muscle fibres having comparatively slow contraction rate. These contain the red heme-protein called **myoglobin**. It can bind oxygen as **oxymyoglobin** that can be stored in red muscle fibres. These are rich in mitochondria. Red muscle carry out arobic contractions without accumulating lactic acid. Therefore red muscle fibres can contract for prolonged durations without fatigue. These are found in muscles which perform sustained work at a slow rate over a prolonged period. Extensor muscles on the back and some flight muscles in birds are examples of red muscles.

2. White muscle fibres - These are also called **fast muscle fibres**. These fibres are much thicker, lighter in colour, free of myoglobin and poorer in mitochondria. Their contraction rate is faster. These receive energy from anaerobic glycolysis. Consequently, these accumulate lactic acid in considerable amount during strenuous work and .

soon get fatigued. White muscles adapted for fast and strenuous work for short intervals are made up mostly or exclusively of white muscle fibres.

Oxygen Debt

During strenuous work, the muscle does not get required amount of oxygen supply. It, then contracts anaerobically receiving ATP from anaerobic glycolysis. This causes accumulation of **lactic acid**, the end product of glycolysis.

During recovery stage, the accumulated lactic acid is oxidised by utilizing oxygen in addition to the normal or regular required amount. The extra oxygen consumed during recovery stage is called **oxygen debt** of the muscle.

QUESTIONS

1. List various functions carried out by skeleton and give a specific example of bones that carry out each function.
2. What property is most highly developed in muscle than any other tissue?
3. Explain the structure of a neuromuscular junction.
4. Define the following terms:
   (i)   Aponeurosis
   (iii) Joint
   (v)   Origin
   (vii) Oxygen debt
   (ii)   Insertion.
   (iv)   Motor unit
   (vi)   Tetanus
   (viii) Single muscle twitch
5. What do you understand with 'all or none response'. Explain it with reference to muscle.
6. Describe in brief the role of Ca^{++} ions in muscle contractions and relaxation.
7. Explain in brief.
   (i)   Neuro-muscular junction
   (ii) Threshold stimulus
   (iii) Refractory period
   (iv) Ball and socket joint
   (v)   Pivot joint
   (vi)   Antagonism.
   (vii) Rigor montus
   (viii) Summation
8. Discuss role of following:
   (i) Myoglobin   (ii)   Flexor muscle.
9. Explain, how muscles help in propulsion of hind limb.
10. Explain bones act as lever and joints as fulcrum'.

Reproductive System

Reproduction is the process by which living organisms produce new individuals similar to themselves. While other systems of body ensure survival of the individual, reproduction ensures perpetuation and survival of their race. The general function of reproductive systems is to produce male and female gametes.

1. The male gametes are called sperm. These are produced in the testes of males.
2. The female gametes are called ova. These are formed in the ovaries of females.

MALE REPRODUCTIVE ORGANS

The male reproductive system is associated with
(i) Formation of sperms and
(ii) Transfer and introduction of sperm into the female reproductive tract to facilitate fertilization of ovum.

The male reproductive organs are –
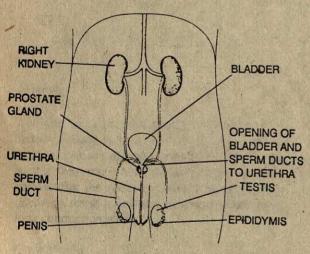
Fig. 25.1   Male Reproductive Organs of Man.

A. Essential Organs - 1. Testes
B. Accessory Organs - 2. Vas deferens
   3. Epididymis   4. Seminal vesicles, and
   6. Ejaculatory duct
C. Supporting organs - Scrotum, Spermatic cords and Penis

1. Testes

In man, testes are two oval bodies about 4-5 cm in length and 10-15 gms in weight. Testes develop in the pelvic cavity in the embryo but by the time baby is born; these move out of the abdominal cavity and lie in a pouch of skin, called scrotum. The scrotum hangs between the thighs. The testes are extra-abdominal because sperm mature at a temperature slightly lower than the body temperature

Histological structure of testes - Each testes is covered with **tunica albuginea**, formed of white fibrous connective tissue. The testis is formed of **seminiferous tubules** and the **interstitial cells** lying between them.

(i) The **seminiferous tubules** are long and coild tubes, lined with a single layer of **germinal epithelium**. Its cells give rise to **spermatogonia** from which sperm are produced.
The long **Sertoli cells** are present among the cells of germinal epithelium in seminiferous tubules. These supply nourishment to the developing sperm.

(ii) The **interstitial cells** or **Leydig cells** secrete male sex hormone - **testosterone** (androgen). It serves following functions:

(a) Promotes development of secondary sexual characters and maintenance of male accessory organs (prostate and seminal vesicles etc.).
(b) Helps to regulate metabolism
(c) Responsible for greater muscular development and strength of males.
(d) Stimulates tubular reabsorption of sodium ions and water and tubular excretion of K^+ ions into the filtrate.
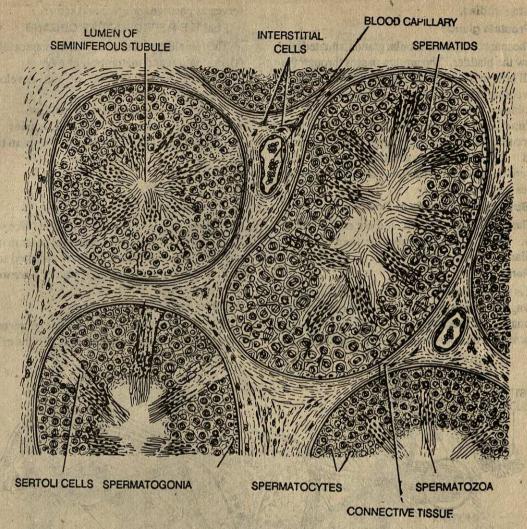
Fig. 25.2 T.S. Testis of a mammal.

2. Epididymis

Each **epididymis** consists of a single tightly coiled narrow tube, enclosed in a fibrous covering. It is about 20 ft. long. It lies along the top and side of testis and is divided into three parts —

(i) head or **caput epididymis**, connected with seminiferous tubules;

(ii) body or middle epididymis and

(iii) tail or **cauda epididymis** connected with vas-deferens.

Functions- Epididymis serves following functions:

(i) Serves as a duct for the passage of sperm from testis to vas-deferens.

(ii) Stores sperms prior to ejaculation.

(iii) Contributes to seminal fluid.

3. Vas Deferens

It is a muscular duct. It comes out of scrotum via inguinal canal into abdomen along with spermatic card.

4. Ejaculatory Duct

Vas deferens along with the duct of seminal vesicle of its side opens into ejaculatory duct. These open into the **urethra**.

5. Seminal Vesicles

These are a pair of convoluted pouches. These secrete viscous fluid which forms much of the

semen. It is rich in fructose and also contains **prostaglandins.**

6. Prostate glands

These are compound tubular glands, situated just below the bladder. The urethra passes through the small hole in the centre of prostate. **Enlargement of prostate in older persons squeezes the urethra and** causes **urine retention.**

Function-Prostate secretes a thin alkaline substance that contributes to the largest part of seminal fluid. Its alkalinity protects sperm from acid present in male urethra and female vagina. It also increases sperm motility.

7. Bulbourethral glands or Cowper's glands

These lie below prostate and are of the size of peas. These also secrete alkaline fluid of semen similar to prostatic fluid.

8. Penis

It is the **copulatory organ** that deposits sperm in the vagina of female. It is formed of three cylindrical masses of erectile tissue, each enclosed in a separate fibrous covering, but held together by a

covering of skin. Urethra passes through penis that serves as passage for urine and semen.

FEMALE REPRODUCTIVE ORGANS

The female reproductive system is associated

(i) Formation and maturation of egg.

(ii) Feeding and protection of the developing embryo inside the womb.

The **female reproductive organs** are –

A. Essential organs - 1. A pair of **ovaries**

B. Accessory organs- 2. A pair of **fallopian tubes**
- 3. Uterus
- 4. Vagina and
- 5. Vulva

1. Ovaries

Human ovaries are a pair of almond - like structures, one on either side of vertebral column in the abdominal cavity. Each ovary is attached to the posterior surface of broad ligament by a **mesovarian ligament.**

Histological Structure

1. The covering of ovary is a layer of **germinal epithelium.** During embryonic life, the cells of
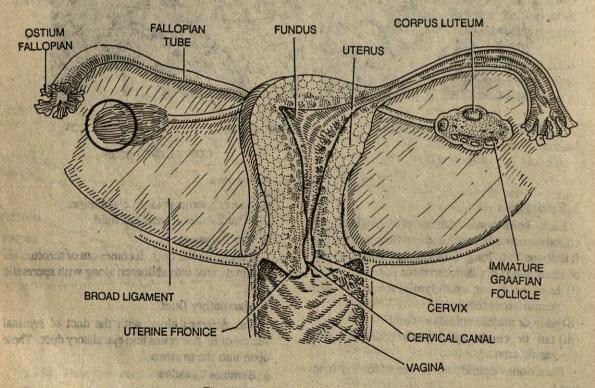
Fig. 25.3 Female Reproductive Organs

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YOUNG
FOLLICLES

OVIGEROUS
CORDS

BLOOD VESSEL
SPROUT

BLOOD VESSELS

STRATUM
GRANULOSUM

CUMULUS
OOPHORUS

ZONA
PELLUCIDA

OVUM

CORONA
RADIATA

ANTRUM

THECA
INTERNA

THECA
EXTERNA
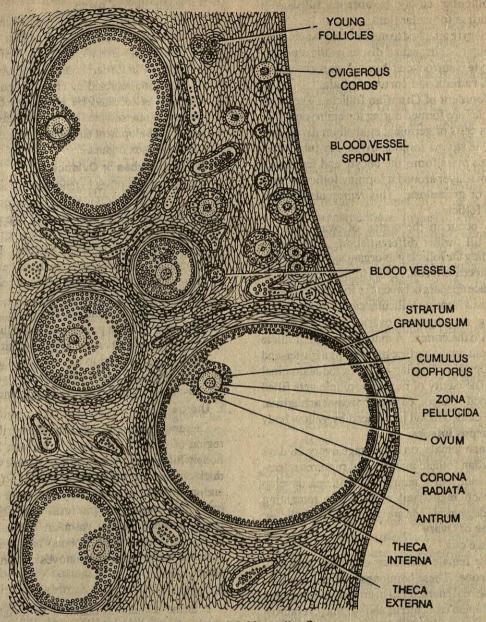
Fig. 25.4 T.S. Mammalian Ovary

germinal epithelium proliferate thousands of **primordial follicles**.

2. The **stroma** is composed of fibrous connective tissue. It is differentiated into outer **cortex** and inner **medulla**.

The **cortex** contains thousands of tiny undeveloped **ovarian follicles**. After puberty, these are present in various stages of differentiation and disintegration. **Medulla** contains only blood vessels and nerve fibres.

Structure of a mature Graafian follicle - A fully mature ovarian follicle is called **Graafian follicle**. Fig.(25.3).It shows following structures –

(i) An outer multilayered **membrane granulosa**,

formed of 2-3 layers of follicle cells.

(ii) A **follicular cavity** or **antrum** filled with colourless follicular fluid.

(iii) An oocyte attached to membrana granulosa by a group of cells, called **discus proligerus**.

(iv) Oocyte is surrounded by **vitelline membrane, Zona radiata** and **corona radiata**.

Development of Graafian follicle - The ovarian follicles are formed during the embryonic life. At places cells of germinal epithelium divide and dip into the stroma forming **ovigerous tube**. One cell of this mass forms the **oocyte** and remaining cells form a layer around it forming **follicular epithelium** or **granulosa**. This represents the **primordial follicle**.

These occur in the cortex of ovary and are retained till further differentiation. The stroma surrounding the follicle gets organized into **external and thecca interna**. As the follicle increases in size a space appears between the follicle cells which increases forming follicular cavity or antrum.

During development ovarian follicle moves deeper into the cortex. A mature Graafian follicle projects out on the surface of ovary as a blister-and finally ruptures releasing ovum in the abdominal cavity. The cavity of ruptured follicle gets filled with blood called **corpus haemorarhagium**. Soon the clotted blood is replaced by yellow body called **corpus luteum**.

In human female, on an average every 28 days one Graafian follicle matures and ruptures releasing an ovum, but a number of follicles develop during each **menstrual cycle**. The remaining follicles degenerate and are called **atretic follicles**.

Functions of Ovary

(i) Produce ova.

(ii) Secrete female hormones-**estrogens** and **progesterone**. These hormones control (a) secondary sexual characters, (b) growth development of fallopian tube, uterus and vagina (c) controls menstrual cycle (d) changes and development of mammary glands.

Hormonal control on Maturation of Graafian Follicle

A. **Ganadotropins** secreted by anterior lobe of pituitary control the over all functioning of ovary.

1. FSH of anterior pituitary stimulates growth and development of Graafian follicle and maturation of ovum.

2. LH of anterior pituitary stimulates **ovulation** (i.e rupture of Graafian follicle, release of ovum), formation of **corpus luteum** and secretion of **progesterone** (a hormone secreted by corpus luteum).

B. **Esterogens** secreted by interstitial cells and progesterone secreted by corpus luteum control the development and functioning of female secondary sex organs.

2. Fallopian Tubes or Oviducts

A pair of these tubes extend from ovary to the uterus. Each can be divided into three parts-

(i) **Infundibulum** - It is the funnel like structure lying close to the ovary. Its opening into the peritoneal cavity is called **ostium**. It is surrounded by finger-like projections called **fimbrae**. Infundibulum collects ovum released in the periotoneal cavity.

(ii) **Ampulla**- the middle dialated part.

(iii) **Isthmus** - the last part that opens in the uterus. The fallopian tubes are kept in position by a mesentery attached to the uterus. These have thick muscular wall, which shows peristaltic movement that propel the egg downward.

3. Uterus

Uterus is a pyriform muscular organ in the pelvis region of female. Its upper broad part is called **body** while the narrow lower part the **cervix**. The thick uterine wall has three layers - (i) Inner **endometrium** (ii) middle **myometrium** and (iii) outer incomplete **parietal peritoneum**. Endometrium is highly vascular. Uterus harbors the developing embryo (foetus) and provides it nutrients and oxygen and removes carbon dioxide and wastes.

4. Vagina

It is the copulation chamber in female. The cervix of uterus projects into upper part of vagina. Vagina opens out. The vaginal opening is situated in the vestibule between the labia minora of the vulva.

In the virginal state, a thin membranous diaphragm-the **hymen** is present at the vaginal orifice.

In female the urethra and vagina have separate openings.

5. Vulva

It is the external female genital organ. It includes **vaginal orifice, labia magora, labia minora, clitoris and Bartholin glands.** The opening of vagina is closed by two muscular folds of Skin, the labia magora. Inside these are a pair of **labia minora.** A sensitive eretile organ about the size of pea is present at the junction of two labia minora. It is **clitoris** and is homologous to male peins.

The **Bartholin's glands** or the **greater vestibular glands** are two bean-shaped glands, one on either side of vaginal orifice. These secrete lubricating fluid and open into the vestibule.

FEMALE SEXUAL CYCLE

In female placental mammals reproduction is an orchestrated process. It needs coordinated preparation of many tissues, starting from maturation of ovum, its release, its transportation, fertilization and preparation of uterine wall to receive the developing egg and its implantation in the uterine wall. Each time the ovum starts maturing, the secondary sex organs also commence some growth changes and prepare for receiving expected fertilized ovum for anticipated pregnancy. Ovum remains alive inside the female tract for only a couple of days. In case fertilization fails to occur within this period, egg shrivels off and in case of no pregnancy, these organs undergo breakdown of their overgrown tissues. This marks the end of the cycle and fresh cycle begins again.

The preparations for reproduction are cyclic. A sexual cycle or reproductive cycle is called **estrous cycle** in all mammals except primates where it is called menstrual cycle. Based on the number of estrous cycles in one year, some mammalian species are **monoestrous** (having one breeding season or estrous cycle per year) or **polyestrous** (having several breeding seasons in a year). Majority of mammals are **diestrous** or **polyestrous.** Human females are polyestrous.

MENSTRUAL CYCLE IN WOMAN

In women, reproductive phase begins with the onset of **menses** at about the age of 13 years. It ends with their cessation (**menopause**) at about the age of 45-49 years. During reproductive phase cyclic changes recur almost after every 28 days in the ovary and walls of uterus only in case fertilization fails to occur. One reproductive cycle or sexual cycle has two notable events –

1. **Ovulation** midway in the cycle.
2. **Menstruation** at the end of the cycle.

The cyclic changes are controlled by specific hormones. To understand the inter-relationship between ovarian and menstrual cycles and the role of hormones, a menstrual cycle is separated into following phases-
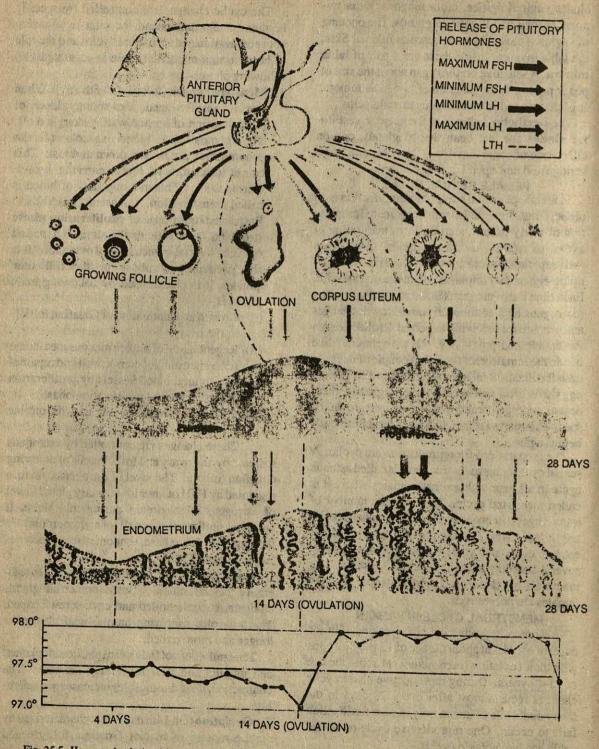
1. **Menstrual phase** (from 1st to 5th day)- When egg is not fertilized, the spongy layer of endometrium of uterine wall is sloughed off. The glands and blood vessels of the endometrium are broken down and lost. This causes discharge of blood carrying broken uterine tissue. This monthly flow of blood is called **menstruation.** (mensem - month).

2. **Postmenstrual phase** or **proliferation phase** (from 6th-13th/14th day) - It is the period between the end of menses and ovulation. It is the **preovulatory phase** or the **follicular phase.** It is charaterised by following main changes –
   (i) Growth and maturation of Graafian follicle in the ovary.
   (ii) Regeneration of broken mucous membrane (endometrium) of uterine wall and repair of its ruptured blood vessels by proliferation of tissues (hence proliferation phase).
   (iii) Growth of endometrium and its uterine glands.

   These changes are controlled by **estrogens** secreted by the ovary and follicle cells of maturing Graafian follicle. The level of estrogens is in turn regulated by **FSH** of anterior pituitary gland. Level of estrogens is maximum during this phase. It enhances proliferation of cells of endometrium. By the end of this phase, endometrium becomes 2-3 mm thick.

   Contraction of uterine muscles increases considerably 2-3 ml. thick. The endometrial glands elongate, become coiled and cork-screw-shaped. The arterioles supplying uterine wall also grow longer and more coiled.

   The epithelium of Fallopian tube gets thickened and its cilia and their movement increases. The contraction of uterine muscles increases considerably.

3. **Ovulation** (On 14th day) - It is characterised by the rupture of mature Graafian follucle and

RELEASE OF PITUITORY HORMONES

MAXIMUM FSH

MINIMUM FSH

MINIMUM LH

MAXIMUM LH

LTH

ANTERIOR PITUITARY GLAND

GROWING FOLLICLE

OVULATION

CORPUS LUTEUM

Progesterone

28 DAYS

ENDOMETRIUM

14 DAYS (OVULATION)

28 DAYS

98.0°

97.5°

97.0°

4 DAYS

14 DAYS (OVULATION)

Fig. 25.5 Hormonal relationship and changes in ovarian follicle and uterine endometrium during one menstrual cycle.

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release of ovum in the body cavity. This is called **ovulation**. It usually occurs on 14th day in a 28-day menstrual cycle.

Final maturation of follicles, and ovulation are under the control of **luteinizing hormone** (LH).

4. **Postovulatory or Premenstural phase** (15th-28th day)

It is the period between ovulation and onset of menses i.e. it marks the end of menstrual cycle. During this period cells of ruptured follicle enlarge and form golden coloured **corpus luteum**. It grows for about 7 days and secretes **progesterone**. The secretion of progesterone and its level in blood is controlled by L.H. In case ovum is not fertilized, the corpus luteum degenerates into a white mass, **corpus albicans**. This lowers down level of progesterone in blood.

Progesterone further prepares the uterus for the anticipated pregnancy. The uterine endometrium thickness further upto 4-5 mm. The uterine glands increase in length and diameter and become more cork-screw shaped. These begin to secrete a juice or fluid in the uterus for nourishing the dividing egg. The uterine movements are reduced thus completing preparation for implantation of the embryo. Progesterone also inhibits further follicular maturation.

This phas is also called the **luteal phase** because corpus luteum is formed and is functional only during this phase. It is called **progesterone phase** because progesterone level is highest during the phase. The name **secretory phase** is given because during this phase uterine wall secretes some nutritious fluid in the uterus. The duration of this phase is pretty constant lasting usually 14 days (*i.e.* from 15th to 28 day) in a 28 days cycle.

Hormonal control of Cyclic Changes in Overies and Uterus

In the nonpregnant female, the cyclic changes in the ovary and uterus are under the control of estrogens and progesterones hormones whose secretion is under the control of **gonadotropic hormones** secreted by anterior pituitary.

1. During menstrual phase the level of estrogens and progesterons falls considerably. This induces adenohypopsis to secrete FSH and LH.

2. Increased level of FSH during early postmenstrual phase stimulates one or more primary ovarian follicles to start growing. It also stimulates follicle cells to secrete **estrogens**. The level of estrogens in blood increases gradually for few days and is at the peak on 12th cycle day.

   The **estrogen surge** reduces FSH secretion and this in turn introduces 'LH surge' within 12 hours *i.e.* on 13th cycle day LH level in blood is at peak. FSH and LH act as synergists.

3. LH causes ovulation. (LH is also called **ovulating hormone**) and formation of corpus luteum.

4. During post ovulatory phase (i.e. from 15th day onwards) corpus luteum secretes **progesterone**. Blood level of progesterone rises rapidly after LH surge and remains high for about a week and then decreases to a very low level approximately 3 days before menstruation starts again. Estrogen level also remains low during luteal phase.

5. The low level of estrogens and progesterone stimulates secretion of FSH and LH from anterior pituitary initiating the next ovarian cycle.

If fertilization of ovum occurs, the menstrual cycle is modified as follows—

1. Corpus luteum persists and secrets progesterone and estrogens during pregnancy period. Fall in progesterone level during early months of pregnancy due to any reason leads to spontaneous abortion.

2. Fertilized egg starts developing and simultaneously travels down gets implanted in the uterine endometrium.

1. Describe reproductive organs in human male.
2. Discuss role of testes.
3. Describe structure of a mature human sperm.
4. Describe process of spermatogenesis.
5. What is estrous cycle?
6. Differentiate between estrous and menstural cycle.
7. Describe differences between male and female urethra.
8. Discuss role of-
   (i) Cells of Leydig
   (iii) Fallopian tube
   (v) Follicle cells
   (vii) Sertoli cells
   (ii) Corpus luteum
   (iv) Endometrium of uterine
   (vi) Epididymis
   (viii) Prostate glands.
9. What are bulbo-urethral glands. Describe their occurrence and functions.
10. Give general functions of testosterone/progesterone.
11. Explain the following-
    (i) First half of menstrual cycle is called proliferative phase as well as follicular phase.
    (ii) FSH and LH are synergetic.
    (iii) Failure of testes to descend outside the body cavity into scrotum produces male sterility.
    (iv) Second phase of menstrual cycle is called luteal phase as well as the secretory phase.
    (v) Gonadotropins have a negative feedback control.
    (vi) LH is also called as ovulating hormone.
12. Discuss mechanism that controls menstruation.
13. Describe histological details of testis/ovary.
14. Name the periods in menstrual cycle with approximate length of each cycle in days and the important events.
15. Describe role of uterus and vagina.
16. What is Graafien follicle? Discuss its formation and ovulation.
17. Draw well labelled diagram of T.S of ovary or testis.
18. Describe role of sartolli cells?
19. Distinguish between -
    (i) Corpus luteum and corpus albicans
    (ii) Spermatogenesis and oogenesis
    (iii) Ovarian follicle and Graafian follicle.
    (iv) Proliferative and secretory phases of menstural cycle.
    (v) Estrogens and progesterone.
    (vi) Primary and secondary sex organs.
20. Define the following-
    (i) Menstruation
    (iii) Monoestrus
    (v) Corpus luteum
    (vii) Sexual dimorphism
    (ix) Spermeogenesis
    (ii) Estruous cycle
    (iv) Atretic follicle
    (vi) Semen
    (viii) Spermatocyte
    (x) Polar body
21. Match the following
    1. Acrosome
    2. Manchette
    3. Leydig cells
    4. Secretory phase
    5. Endometrium
    6. FSH
    7. Spermiogenesis
    8. Proliferative phase
    9. Isthmus
    10. Progesterone
    (a) Spermatid.
    (b) Uterus
    (c) Mitochondria
    (d) Estrogens
    (e) Spermatozoan
    (f) Follopian tube
    (g) Testosterone
    (h) Corpus luteum
    (i) Progesterone
    (j) Adenohypophysis.
22. Describe hormonal control of maturation of Graafian follicle and process of ovulation.
23. Describe hormonal control of male reproduction.
24. Describe changes in the following organs during luteal phase/proliferative phase of menstrual cycle.
    (i) Ovaries
    (iii) Fallopian tubes.
    (ii) Uterus
25. Where are Leydig cells are found and what is their importance in sexual reproduction.

☐ ☐

Embryonic Development

PHASES OF EMBERYONIC DEVELOPMENT

The embryonic development in all the sexually reproducing metazoans begins from a single cell and follows the same fundamentally similar sequence of events. It includes-

(1) Formation and differentiation of sex-cells or gametes - **Gametogenesis.**

(2) Fusion of male and female gametes to form zygote - **Fertilization.**

(3) Division of zygote - **Cleavage.**

(4) Formation of hollow ball of cells - **Blastulation** (Formation of blastula).

(5) Movement and rearrangement of embryonic cells to form three primary germinal layers - **Gastrulation.**

(6) Differentiation and development of organ system from the primary germinal layers-**Organogenesis** or **Organ formation.**

(7) Acquisition of characteristic morphological features of the organism-**Differentiation and morphogenesis.**

(8) Increase in size all through the development and afterwards-**Growth.**

Gametes and Gametogenesis

The process by which gametes are produced in the gonads is known as **gametogenesis.** The process of formation of male gamete or sperm is called **spermatogenesis** and that of female gamete or ovum as **oogenesis.** The gametes are the only link between generations and their nuclear DNA is the depository of all those genetic information that are needed in the development of new organisms. During gametogenesis the germ cells undergo meiosis so that in the gametes the number of chromosomes is reduced to half. Therefore, the gametes are **haploid** whereas parent cells are diploid.

Spermatozoa and Spermatogenesis

The spermatozoa or male gametes are solitary cells specialized for swimming and delivering itself into the ovum to complete the act of fertilization. A human spermatozoon consists of four parts-the **head, neck, middle piece** and a **tail or flagellum.**

1. **Head**-The head is almost conical in the human spermatozoa. It is formed of **acrosome** and **nucleus** enclosed in a thin membrane.

   (i) The **acrosome** forms a cap-like structure **(head cap)** at the anterior end of the nucleus. It is formed from the Golgi complex and helps the spermatozoon to penetrate through the egg membranes and enter the egg cytoplasm. It secretes **tissue-dissolving** (lytic) **enzymes** to facilitate this function.

   (ii) The **sperm nucleus** contains densely packed DNA and proteins. The DNA is present in the quiescent state. Its posterior margin is depressed to accommodate the **proximal centriole.**

2. **Neck**-In some spermatozoa the head is followed by a short neck. It consists of just two granules or centrioles. These are called **proximal centriole** and **distal centriole** and lie in the depression of the nucleus. It is introduced into the egg at the time of fertilization along with sperm nucleus. It is necessary to initiate cleavage or division in the zygote.

   The **distal centriole** lies posterior to the proximal centriole and acts as a **proximal granule.** It provides attachment to the axial filament of the sperm tail or flagellum.

3. **Middle piece**-The middle piece consists of apical part of the axial filament surrounded by a tightly coiled spiral sheath of elongated **mitochondria.** The mitochondria contain oxidative enzymes and provide energy for sperm motility.

   A thin sheath of cytoplasm around the mitochondria and plasma membrane is called **machette.**

4. **Tail or flagellum**-It consists of a central **axial filament,** thin layer of **cytoplasm** and an outer smooth **plasma membrane.** The axial filament is formed on nine pairs of **longitudinal fibres** which extend upto the tip of axial filament. In mammalian sperm another set of nine

much thicker or band-shaped fibres is present outside the longitudinal fibres. These fibres do not reach the tip of sperm tail. The free end of sperm tail without additional fibres is called **end piece**.

Spermatogenesis

The maturation of spermatozoa develop from sperm mother cells or **spermatogonia** of the germinal epithelium that lines the seminiferous tubules. The process of spermatogenesis is divided into following heads:-

1. Multiplication phase
2. Growth phase
3. Maturation phase
4. Metamorphosis of spermatid.

1. **Multiplication phase**-The spermatogonia or sperm mother cells divide repeatedly by mitosis producing new sex-cells. Some of these sex-cells move towards the lumen of seminiferous tubules and enter growth phase. These are called **primary spermatocytes**.

Some sex cells produced by the division of spermatogonia remain in their original condition and continue to divide giving rise to primary spermatocytes. Such cells are known as 'stem cells'.

2. **Growth phase**-During growth phase, the spermatocyte as well as its nucleus enlarge in size.

The primary spermatocyte is ready to undergo maturation division.

3. **Maturation phase** - Each primary oocyte undergoes first maturation division which is a **reduction division** and two daughter cells are formed, each with n number of chromosomes. The daughter cells are called **secondary spermatocytes**.
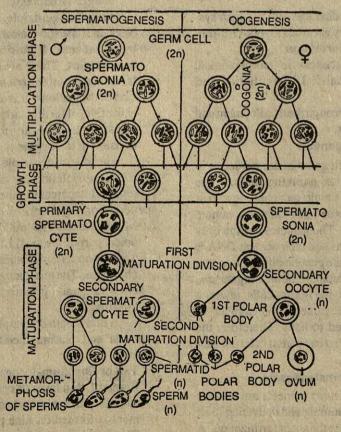
Fig. 26.1 Diagram to compare mechanism of spermatogenesis and oogenesis

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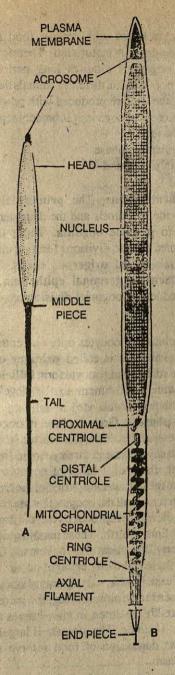
Fig. 26.2 Electron microscopic structure of mammalian sperm.

PLASMA MEMBRANE
ACROSOME
HEAD
NUCLEUS
MIDDLE PIECE
TAIL
PROXIMAL CENTRIOLE
DISTAL CENTRIOLE
MITOCHONDRIAL SPIRAL
RING CENTRIOLE
AXIAL FILAMENT
END PIECE

Secondary spermatocytes undergo **second maturation division**. It is a simple mitotic division. the four daughter cells formed are known as **spermatids**. Thus from each primary spermatocyte four spermatids are formed.

4. **Metamorphosis or spermiogenesis** - The spermatid formed as a result of maturation divisions is a typical animal cell with all those cell organelle as present in an animal cell. In this form it cannot function as a male gamete. During the metamorphosis of a nonmotile spermatid into a motile spermatozoon following changes take place –

(1) The **nucleus** shrinks by losing water, RNA and other accessory materials. The DNA becomes closely packed.
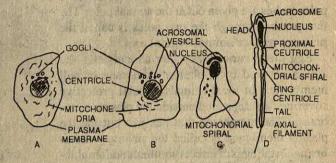
Fig 26.3 : Diagram Showing Maturation Of sperm From Spermatid.

(2) An **acrosome** is formed from Golgi complex of the spermatid.
(3) The **axial filament** of the tail of **spermatozoon** is formed from the distal centriole of the spermatid.
(4) The **mitochondrial spiral** is formed from the mitochondria. This sheath is known as **nebenkern**.
(5) Much of the **cytoplasm** of spermatid is lost and the remaining cytoplasm forms a sheath around the mitochondrial spiral. This sheath is known as **manchette**.

During the process of differentiation the developing sperm have their head embeddad in the **Sertoli cells** from which they obtain their nourishment.

Ovum and Oogenesis

The ovum or female gamete is much larger. It is non-motile and laiden with different types of energy rich materials like yolk, glycogen and proteins accumulated in its cytoplasm during its growth.

Size-The size and yolk contents vary considerably in eggs of different animals ranging from 10μ

to few centimetres. A mature ovum in all animals is much larger than the ordinary cell.

Structure-The ovum is usually spherical or oval. Its cytoplasm contains reserve food material in the form of yolk, glycogen and proteins, RNA molecules and pigment granules. The distribution of material is not uniform so that the egg is rather a polarized structure with one pole being different from the other. These are named as **animal pole** and **vegetal pole** respectively. The nucleus lies in the animal pole. During maturation of ovum, the polar bodies are given out at the animal pole. The line passing through the two poles is called the **primary axis** or **animal vegetal axis**.

Egg membranes-Like other animal cells, the egg is covered by a plasma membrane or cell membrane. In most animals, special protective coverings are deposited outside the plasma membrane. The membrane that lies just outside the plasma membrane is called the **primary membrane**. In the eggs of insects, molluscs and amphibian this membrane is thin and smooth and is called **vitelline membrane**, whereas in the eggs of fish, reptiles and birds it bears striated appearance and is called **zona radiata** and in the eggs of echinoderms it is jelly like.

The membrane secreted outside the primary egg membrane by a layer of follicle of the ovary is the **secondary egg membrane**. It is in the form of a chitinous shell in insect eggs **(chorion)**. **Tertiary egg membranes** are secreted by the wall of oviduct or some other maternal tissue. These may be in the form of albuminous layer or jelly or the egg membranes and shell as found in the eggs of reptiles and birds.

Nucleus-The nucleus of a mature ovum is in the metaphase of second maturation division.

Functions of Egg

The egg in the form of female gamete serves following purposes-

1. Supplies one complete haploid set of chromosomes from female parents to the future embryo.
2. Supplies all the cytoplasm to the embryo.
3. Supplies reserve food material for the developing embryo (in oviparous only).

Oogenesis

To perform above functions, the egg cell is enlarged, is packaged with reserve food and is programmed during its maturation. Therefore, the process of oogenesis requires long period and differs in minor details in different animals depending whether the ova are produced with or without yolk. The process of oogenesis is broadly separated into three phases-

1. Multiplication phase
2. Growth phase, and

1. **Multiplication phase**-The **primoridal germ cells** divide by mitosis and the daughter cells detach to produce **oogonia**. These divide by repeated mitotic divisions forming clusters of oogonia called **ovigerous cords**. These lie adjacent to germinal epithelium. The final products of oogonial division are called **occytes**.

In each cluster of oocytes only one enters the growth phase and is called **primary oocyte** while the surrounding oocyte form **follicle cells** and provide nourishment to the developing ovum (the primary oocyte).

2. **Growth phase** - Growth phase in oogenesis is very long and elaborate. It varies from few days to many years *e.g.* three years in frog. In mammals, the proliferation of oogonia is restricted to the intrauterine period of the embryo. In human female all the oocytes that are released through the entire reproductive cycle are present at the time of birth. These remain quiescent till puberty for about 12-14 years. During growth phase following changes occur.

(i) **Increase in size** - The primary oocyte increases manyfolds. In frog, the increase is about 27,000 times, in man 7 times and in mice 34 times. The increase is largely due to the deposition of food reserve in the ooplasm.

(ii) Increase in the number of mitochondria.

(iii) Increase in the amount of ER.

(iv) Increased activity of Golgi complex.

(v) **Vitellogenesis** (Synthesis of yolk)-The growth of oocyte is mainly due to the deposition of yolk in the ooplasm. Chemically yolk is **lipoprotein** composed of proteins, phospholipids and neutral fats
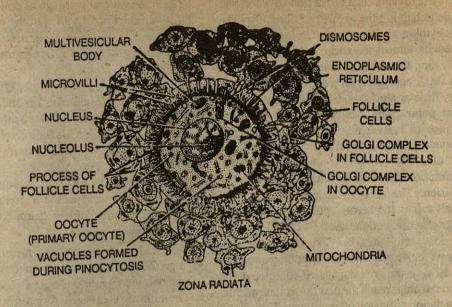
Fig. 26.4 Mammalian Ovum

along with small amount of glycogen. The yolk is either synthesized in the liver of female parent in soluble form. Through circulation it is transported to the follicle cells that surround the maturing ovum. From follicle cells it is absorbed by the ovum, and is deposited in the form of yolk platelets and granules in the ooplasm. The mitochondria and Golgi complex are said to bring in the conversion of soluble form of yolk into insoluble granules or platelets.

(vi) Formation of a thin vitelline membrane around the oocyte.

(vii) **Increase in the size of nucleus**-Due to increase in the amount of nucleic acids and nuclear sap, the nucleus of oocyte in this stage is called **germinal vesicle**.

(iii) In large yolky eggs of insects, fish, reptile and birds the chromosomes of oocyte increase greatly in length and develop long side loops to facilitate rapid synthesis of yolk. These chromosomes are called **lampbrush chromosomes.**

(ix) Increase in the size and number of nucleoli.

(x) **Gene-amplification**-During growth phase the nucleolar genes that code for ribosomal RNA and are located in the nucleolar organizer region multiply to facilitate rapid synthesis of ribosomal RNA. This multiplication of genes without mitosis is called gene amplification or **redundancy.**

3. **Maturation** - During maturation the nucleus of oocyte undergoes two maturation divisions.

Table 26.1: Differences between Spermatogenesis and Oogenesis

Spermatogenesis	Oogenesis
1. Four spermatids are formed from one sperm mother cell.	1. Only one ovum is formed from one primary oocyte and the other cells are extruded out as polar bodies.
2. The sperm mother cell divides into four equal cells and all four are reproductive units.	2. The oocyte divides unequally into two. The one with practically all the cytoplasm forms the secondary oocyte which again divides unequally. The smaller cells are named as polar bodies which are inert and thrown waste.

The first division is a **reduction division** and leads to halving the number of chromosomes. The cytokinesis is unequal. The large daughter cell with almost the entire cytoplasm and all yolk etc., forms the **secondary oocyte**, while the small cell just with a haploid nucleus and very little or almost no cytoplasm is called the **first polar body**. It is given off from the surface of oocyte at the animal pole. The secondary oocyte, therefore, contains haploid set of chromosomes. It undergoes second maturation division or the second meiotic division. The division is also unequal. The small cell is the **second polar body** and the large one is called **ovum**.

In most vertebrates, the first meiotic division begins with the commencement of growth and by the time the growht phase is completed, the chromosomes reach the diakinesis state and the first meiotic division is completed. The second maturation division occurs only when egg is activated by the entry of sperm.

Fertilization

As a result of copulation, semen containing sperm is ejaculated in the vagina. The sperm migrate up through uterus into the follopian tube.

As a result of ovulation egg is released in the abdominal cavity. The cilia of fallopian tube produce a current by which egg enters the oviducal funnel. It travels down the fallopian tube. Here it gets surrounded by a number of sperms, but only one of them fuses with the egg. The acrosome of sperm produces enzyme **hyaluronidase** which dissolve mucus and egg membranes, making passage for the sperm nucleus into the egg cytoplasm.

The fusion of sperm nucleus with egg nucleus is called **fertilization** and **zygote** is formed. In all mammals fertilization is **internal**. In fishes and amphibians fertilization is **external** as the egg is fertilized outside the body.

Artificial Insemination

The deposition of sperms in the vagina by artificial means is called **artificial insemination**. This is widely used in the improvement of farm animals like cow, buffalo, horse, pig etc. The method involves the following steps-

(a) Collection of semen from desired male by artificial means.

(b) Preservation or storage of collected semen.
(c) Introduction of semen in the vagina.

Use of Artificial Insemination - This method of initiating pregnancy in farm animals has two advantages:

(i) The spermatic fluid (semen) from a desired or good quality male (bull or stallion male horse) can be used to inseminate a number of females.
(ii) Preserved spermatic fluid can be transported to distant places instead of transporting the male animals.

Under medical supervision the artificial insemination may be used in case of sterile males or males producing semen of low sperm count.

Early Development

The division of zygote by mitosis is called **cleavage**. During its journey down the fallopian tube to uterus, the zygote undergoes repeated equal and **holoblastic cleavages**. As a result a ball of cells is formed. It is called **morula**. At this stage, embryo reaches uterus and gets attached to uterine wall. This process is called **implantation** and embryo is called **foetus**.

Once the extra embryonic membranes are formed, numerous finger-like projections arise from the **allanto-chorion**, that surrounds the foetus.

The development in mammals occurs inside the body of female. The egg is small with very little or practically no yolk. It is described as **microlecithal** and **isolecithal**.

1. **Segmentation** - Segmentation starts about 14-15 hours after fertilization while the egg moves down through fallopian tube. The divisions are **mitotic** and are called **cleavages**. Mammalian zygote undergoes **holoblastic** and **equal cleavages**.

The **first cleavage** furrow is vertical passing through the imaginary axis that runs through animal pole to vegetal pole. The two daughter cells formed are called **blastomeres**. The second cleavage is also vertical but at right angle to the first one forming four of equal size. Subsequent divisions occur one the the other in an orderly fashion. Division are rapid and the daughter blastomeres become progressively smaller. During cleavage, the
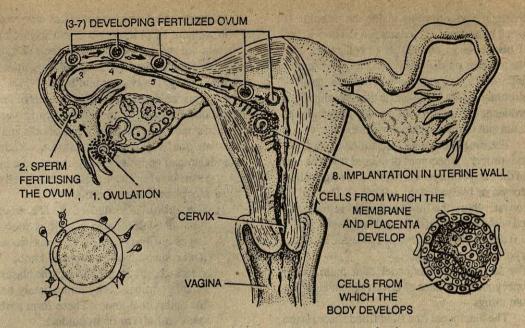
Fig. 26.5 Site of fertilisation of egg and implantation of embryo

number of cells in the embryo increases but the size of the embryo remains unchanged.

2. **Morula-** After repeated cleavages, the embryo takes the form of a solid ball of cells, and looks like a mulberry. This embryonic stage is called **morula** (a little mulberry).

3. **Blastula** or **Differentiation of Blastodermic Vesicle** - As the cells of morula continue to
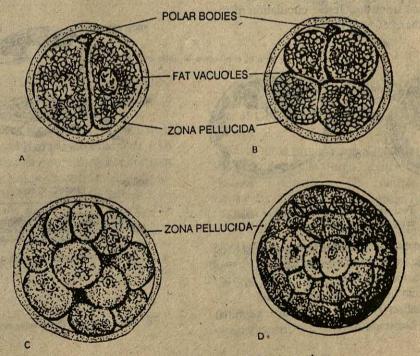
Fig. 26.6 Stages in the development of human embryo

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divide, a cavity appears inside the morula. It forms **blastocoel**. It separates a **surface layer of blastomeres** and an **inner cell mass**. The blastomeres on the surface of embryo become flattened and form **trophectoderm** or **trophoblast**. This layer on further development produces extra embryonic membranes and placenta and helps in nourishing the embryo.

The **inner cell mass** is destined to form the embryo proper. It becomes displaced towards one end of the early embryo which is at this stage called **blastocyst** or blastodermic vesicle The end of blastocyst, where the inner cell mass remains attached with trophoblast cells, forms the **embryonic pole**. It develops and becomes the dorsal side of the embryo.

The large sized blastocoel of a mammalian embryo at this phase of development signifies two things –

1. The blastocoel (the fluid filled space) is the site where embryos of ancestral forms lodged food material in the form of yolk.

2. The blastocoel in the embryo increases in size due to accumulation of more and more fluid. This increases the outer layer of **blastodermic vesicle** or **blastocyst** for drawing food for the yolkless embryo collected from the uterine circulation of the mother.

process in the development which involves the movement of prospective organ formic areas from the surface of blastula to their definitive positions in the embryo and their reorganization into three primary germinal layers.

It means during **gastrulation** cells of undifferentiated blastula or the blastodermic vesicle move in small masses to form sheets of cells and differentiate into three germ layers *i.e.* **ectoderm mesoderm** and **endoderm**. These are called **primary germs layers**. These movements of cells are called **morphogenetic movements**.

(i) **Formation of endoderm** - The enlargement of blastodermic vesicle is soon followed by proliferation of cells from the lower surface of embryonal knob. The detached cells are pushed into the blastocoel or subgerminal cavity immediately below the embryonal knob. These form **embryonal endoderm** or **hypoblast**.

Section of the embryo at this stage shows a tube enclosed within a tube. This inner tube is bounded by **endoderm**. It forms the **primitive gut**. At a later stage, the primitive gut differentiates into two parts. The part of gut in the embryonal part

Fig. 26.7 Two stages in the development of blastodermic vesicle or blastocyst

With the completion of differentiation of blastodermic vesicle within mother womb. The blastodermic vesicle gets attached with the endometrium of uterus through placenta.

4. **Gastrulation** (Formation of three germinal layers) - **Gastrulation** is an important dynamic
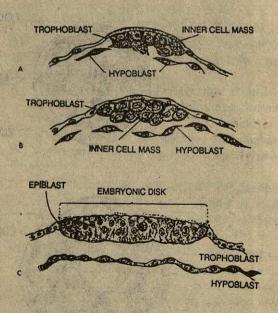
Fig. 26.8 Stages in the development of endoderm
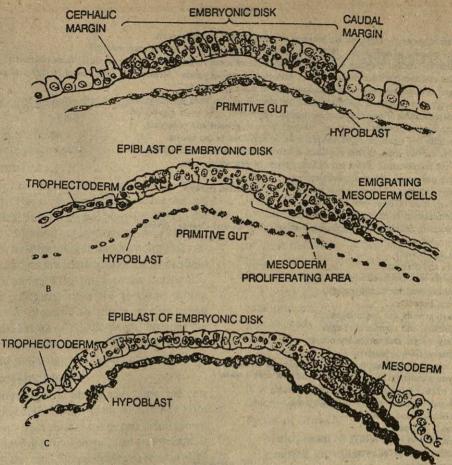
Fig. 26.9 Stages in the formation of mesoderm in a mammalian embryo.

forms the gut tract. The other portion as a distal sac forms **yolk sac** that communicates with the gut of embryo.

(ii) **Formation of mesoderm** - After the completion of endoderm as a cellular layer, cells at the candal margin of embryonic disc start proliferating at an increased rate. Such proliferation of cells results in localised increase in the thickness of the disc. The proliferated cells detach from the embryonic disc and form mesodermal layer.

(iii) **Formation of ectoderm** - After the formation of mesoderm the remaining cells of the embryonic disc arrange themselves in a layer to form the ectoderm.

Fate of Germinal Layers in Embryonic Development

These three primary germs layers give rise to definitive organ and organ system during post gastrular development. For example, the **ectoderm** cells form skin and its appendages and the nervous system. The **mesoderm** differentiate into muscles, bones, connective tissues and the organs of excretion and reproduction and **endoderm** forms epithelium of diagestive and respiratory tracts etc.

QUESTIONS

1. What is Gametogenesis? Differentiate between oogenesis and spermatogenesis.
2. Describe the process of oogenesis. How many ova are formed from a single primary oocyte?
3. With the help of labelled diagram discuss the mechanism of spermatogenesis. How does it differ from oogenesis?
4. Describe the electron microscopic structure of mature mammalian sperm. Mention the functions of its different parts.
5. Compare and contrast the process of gametogenesis in male and female.
6. Briefly describe the process of spermatogenesis in animals. What is its significance?
7. Give the classification of ova based on the amount of reserve flood in its cytoplasm.
8. Describe the similarities and differences between spermatogenesis and oogenesis.
9. Describe briefly the significance of unequal meiotic divisions in the oocyte.
10. Describe the various changes that transform a spermatid into a functional sperm.
11. What are egg membrance? Point out different types of egg membranes.
12. Enlist major phases of embryonic development.
13. Describe development of blastodermic vesicle in a mammalian embryo.
14. Describe formation of three primary germ layers.
15. Explain 'fertilization is physiochemical process'.
16. What is the basic difference between simple mitolic division and cleavage division.
17. Differentiate between
    (i) Morula and blastula
    (ii) Blastula and blastocyst
    (iii) Ectoderm and trophoectoderm
    (iv) Oogenesis and spermatogenesis
18. Differentiate between:-
    (i) Spermatogenesis and spermiogenesis
    (ii) Mesolecithal and marolecithal eggs
    (iii) Primary oocyte and secondary oocyte
    (iv) Vitellogenesis and maturation.
19. Describe role of Golgi complex in the formation of acrosome.
20. What do you understand by vitellogenesis and how does it occur?
21. Trace the relationship between the following terms :-
    (i) Lampbrush chromosomes and vitellogenesis
    (ii) Mitochondria and manchette
    (iii) Ogenesis and oocyte
    (iv) Oogenesis and polar bodies.
22. Give functions of the following:
    (i) Egg membranes
    (iii) Centriole
    (v) Mitochondrial spiral
    (ii) Acrosome
    (iv) Lampbrush chromosome
    (vi) Seirtoli cells
23. What do you understand by organogenesis and morphogenesis ?
24. Define the following forms:-
    (i)   Sexual dimorphism
    (ii) Hermaphroditism
    (iii) Vitellogenesis
    (iv) Stem cells
25. What is the role of stem cells?
26. What is germinal vesicle ? Where is it found ?
27. What is the difference in an ordinary body cell and a gamete ?
28. In what stage of division is the nucleus of ovum when it is laid down?
29. The spermatogonium in man contains 46 chromosomes; what will be the number of chromosomes in spermatids produced from it?

□ □

Growth, Repair and Ageing

Life history of sexually reproducing animals can be divided into two phases –

1. Embryonic phase
2. Postembryonic phase.

1. Embryonic Phase

The embryonic development includes **morphogenesis** and **differentiation**. These events establish morphological plan of animal body i.e. lead to the formation of different organs and organ-systems in the embryo, transforming it into a young individual. These changes are accompanied by an increase in the size of embryo. But this increase is insignificant when compared with the increase during postembryonic phase. This phase is also called **prefunctional state** of development, because the embryo is dependent on outside energy source either stored in the egg or obtained from mother.

2. Postembryonic phase

The **postembryonic phase** starts from the new born offspring to the death of animal. The new born grows through a set pattern to became a-full grown individual having a final shape, size and weight. It performs all the vital life processes to remain alive and produces individuals of its race. This phase of life cycle is also called **functional state of life**. The changes an organism undergoes during this period are –

1. Increase in the size of organism - **Growth**
2. Repair of constant wear and tear of cells and tissues of the body and replacement of lost parts of body - **Repair** and **Regeneration**.
3. Degenerative changes leading to symptoms of growing old - **Ageing** or degrowth.
4. Degenerative changes causing end of living being's life span - **Death**.

GROWTH

Definition

In simple form **growth** can be defined as *increase in size and weight of an organism due to synthesis of new protoplasm.* All living organisms exhibit growth. It is one of the basic characteristic of life.

Mechanism of Growth

At **cellular level**, growth is increase in the amount of protoplasm. It involves gaining more material from the environment than is given back to it in the form of metabolic wastes. It means during growth, the rate of synthesis of complex molecules of cytoplasm (i.e. proteins, nucleic acids and carbohydrates - **anabolic rate**) is higher than the **catabolic rate** of break down of these substances. Some of these materials - **proteins** provide the building blocks for anabolic reaction, while other substances like **carbohydrates** supply the extra energy.

During growth anabolic process dominates the catabolic activity. Conversel , when decomposition exceeds synthesis, first the internal food reserve (glycogen and fats) is catabolised to run the metabolic machine of body. Next, the energy is obtained from proteins of protoplasm. This causes depletion of living matter. The phenomenon is described as **degrowth**.

Types of Growth

1. **Multiplicative growth** - In multicellular organisms, growth occurs by increase i.. u.e number or size of cells that make up the organism. For example, an adult human is made up of some 60 trillion (6×10^{13}) cells, while the new born baby contains only of about 2 trillions (2×10^{12}) cells. The increase in the number of cells is due to mitotic cell division. In this type of growth, the average cell size remains the same or increases insignificantly. This type of growth is called **multiplicative growth** (growth due to multiplication of cells). Growth of embryos, young ones and prenatal growth in mammal is of this type.

2. **Auxetic growth** - In some organisms (*Ascaris*) growth occurs as a result of increase in the size of their cells. The number of cells remains the same. This type of growth is described as **auxetic growth**. It is found in nematodes, rotifers and tunicates.

3. **Accretionary growth** - During postembryonic growth and also in the adult, all the body cells

are incapable of undergoing division. The differentiated or specialized cells of organs and tissues lose the ability to divide. The undifferentiated cells present at specific locations in the body divide mitotically and help in growth. For example, mesenchyme cells, chondriocytes, and osteocytes etc.

In adults the undifferentiated reserve cells, divide and reinforce and replace the worn out differentiated cells as and when needed. This type of growth is called **accretionary growth.**

Cells Reproduction and Cell Growth.

At cellular level, the growth of multicellular organisms is governed by two main activities -
1. Reproduction of individual cells of body by **mitotic cell divisions.**
2. Growth of cells or increase in the size of cells by synthesizing new protoplasm.

The interphase stage of cell cycle is differentiated into G_1, S and G_2 phases. During these phases new materials such as **nucleic acids** and **proteins** are synthesized and accumulated in the cells so that cells and their nuclei increase in size. The cells can grow upto a limited extent after which these enter cell division.

The growth of individual cells comprising the body is most essential factor of growth in all multicellular animals. After attaining a specific nuclear cytoplasmic ratio, the cells divide and multiply adding to the size of the organism.

The rhythmicity of cell multiplication can be studied in tissue culture or in culture of unicellular organisms.

Growth Rate

Growth is a measurable increase in the mass of living substance. Different animals exhibit different growth rate. Moreover, growth rate in the same individual varies during different periods of life from birth to adulthood.

Growth Curve

The growth rate in an individual at different periods of life can be represented in a curve by plotting the weight of individual at different time intervals (in years) on graph paper. For example, weigh a growing puppy or a human baby from birth till adulthood when growth ceases. Plot the weight in kg. against time in months or years. This gives a **growth curve.** This is a simple S-shaped **sigmoid**

curve, rising slowly of first showing a slow increase in weight of body or size of the body. Then there is a steep rise of the curve for a period and then in the last part the rise of curve gradually slows down and runs parallel to the horizontal base line. The same curve expresses the growth of population.

S-shaped sigmoid growth curve is characteristic of all higher animals including man. The difference between the initial and final weight or initial and final size of an individual, for any period of time is the **absolute increase.**

Phases of Growth

Growth of an organism can be differentiated into following periods -
1. **Lag period** - It is the first period during growth phase. It is characterised by little or no actual growth. During this period, the organism is getting prepared for growth, synthesizing enzymes and accumulating substances to metabolize.
2. **Exponential period** - During this period growth begins, slowly at first and more and more rapidly later on. As a result organism enlarges according to geometric progression doubling and redoubling in size. This is called **exponential growth** or **logarithmic growth** and this phase of growth as exponential or logarithmic phase.
3. **Decelerating growth period** - The exponential
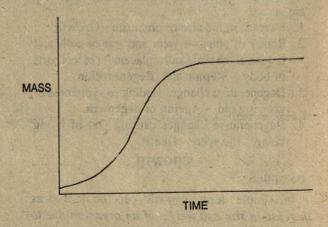
Fig. 27.1 S-shaped growth curve-Sigmoid curve

growth does not continue indefinitely. It is followed by a period when growth proceeds more slowly and finally ceases altogether.

For example, housefly larva doubles its weight every 13 hours. But during decelerating growth phase (pupal stage) growth stops and larva prepares for metamorphosis.

In many organisms growth slows down after exponential phase but never ceases. For example, many fishes and reptiles continue to grow year after year. In mammals including man, growth ceases after attaining a specific size.

During **decelerating phase**, the rate of anabolic activities (**anabolism**) is exactly counterbalanced by rate of catabolic activities (**catabolism**).

Growth in Vertebrate Animals

In animals growth does not occur in localized areas as in plants (apical meristem and cambium).

All tissues and organs of the body grow simultaneously, though at different rates.

Fundamental to the growth of body is growth of its supporting skeleton. Bones are able to grow so long as they have cartilaginous, nonbony region where further cell division and elongation can occur. The growing region of long bones is represented by their epiphyseal ends.

In human beings, growth stops during late teens and early twenties when the growing regions of the bones become fully ossified. The cartilaginous matrix of these regions gets ossified, stopping further growth. This sort of cessation of growth occurs in all other mammals but usually at a younger age.

Differential Growth of Human Body Parts

In human beings similar to other animals different body organs or body parts (head, neck, thorax and limbs etc. do not grow at the same rate. The growth rate of different body parts is different and
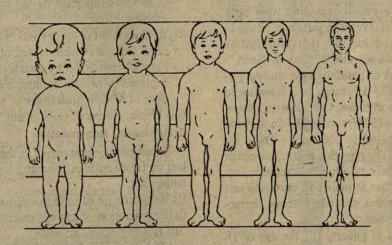
Fig. 27.2 Foetal and postnatal stages of human being drawn to show changes in the proportion of different body parts.

is shown in the table given below —

Table 27.1:
Growth Rate of Different Body Parts of Human Body
From Birth to Adulthood

Body Part	Weight (in kg)	
	Newborn Baby	Adult Male
1. Muscles	0.8	30
2. Skeleton	0.4	10
3. Brain	0.4	1
4. Fat	0.8	10
5. Rest of the body	0.9	19
Total	3.3	70

Fig. 27.2 shows that the trunk and legs grow much faster than the head from infancy to adulthood. The human foetus or a new born baby has an unproportionately large head and comparatively very short legs. Due to slow growth of head and fast growth of limbs during postembryonic phase the body shape and proportion between different parts of body changes.

Hormonal Control of Growth Rate in Man

In **childhood** - a period extending from birth upto 10 - 13 years (10 years in girls and 13 yrs in boys), the growth is quite slow. It is controlled by hormone - **thymosin** secreted by thymus gland.

Towards the end of childhood i.e. during **puberty** (age between 14-18 years), there is enhanced activity of growth hormones - **thyroxin** and **somatotrophic hormone** (STH) secreted by thyroid and anterior pituitary gland respectively. These increase growth rate. The growth rate is maximum or at the peak during puberty. Due to increase in sex-hormones-testosterone in male and estrogens and progesterone in females, secondary sexual characters are also established.

Thus by the end of puberty (by the age of 18 years) the fully grown and sexually mature male and female are formed and by the period physical growth of body starts declining and almost ceases by the age of 22-23 years.

REPAIR AND REGENERATION

Definition

Developmental potentialities persists into the postembryonic period in almost all living organisms, but in majority of forms it is limited to the repair, replacement or renewal of the damaged or lost parts. This may involve replacement of few dead or damaged cells healing of wound replacement of lost parts or regeneration of major parts of the body or the regeneration of whole organism from a mall piece of body or from a few cells. Therefore, regeneration is defined as-

'The process of replacement, repair, restoration or renewal of the damaged or lost parts of the body or the reconstitution of the whole body from a small body fragment during the postembryonic life of an organism.'

A. Types of Regeneration

1. Physiological Regeneration

In the life of an organism there is a constant loss of many kinds of cells due to normal wear and tear caused by day to day activities. Their replacement is known as **physiological regeneration**.

Examples are -

(i) **Replacement of RBCs** - Life span of human RBC is 120 days. These need regular removal and replacement. Worn out RBCs are deposited in **spleen** (=the grave yard), while new RBCs are regularly produced from red blood mother cells (erythropoeitic tissue) of the red bone marrow.

(ii) **Replacement of epidermal cells of skin** - The cells from the outer layers of epidermis are regularly peeled off by wear and fear. These are replaced by new cells added by the division of cells of **Malpighian layer** of skin.

(iii) **Replacement of cells of gut lining**

2. Reparative Regeneration

Reparative regeneration is the replacement of lost parts or repair of damaged body organs. Examples are –

(i) Regeneration of limb in salamanders

(ii) Regeneration of lost tail in lizard

(iii) Healing of wound and

(iv) Replacement of damaged cells.

3. Autonomy

In some animals, some part of the body is broken off the body on being threatened by the enemy or predator. This '**phenomenon of self mutilation of body is called autotomy**'. The lost past may be tail, limb, viscera or arm , e.g.

(i) **Crabs** break off their leg on approaching the enemy

(ii) Lizards throw off its tail.

(iii) **Holothurians** (Echinoderm) throw off their internal viscera (respiratory tree etc.)

(iv) **Starfish** (Echinoderm) can regenerate the whole arm.

Autotomy is a special adaptation for escaping the danger of attack by enemy or predator.

B. Regenerative Capacity in Animal Groups

Regernation in Invertebrates

The capacity of reparative regeneration, though, present throughout the animal kingdom, varies greatly in its course and extent in various animal groups. Among invertebrates, protozoans, sponges and coelenterates the regenerative capacity is very high. In songes, the entire organism is reformed from a group of few cells. This type of regeneration is called **restorative regeneration.** It is also called **morphallaxis or morphallactic regeneration.**

(i) In **sponges** body can be reconstructed from isolated body cells. If a sponge is squeezed in a muslin cloth, its cells gets isolated and squeeze out of the cloth. These cells then rearrange and reorganize to form bilayered sponge bodywall.

(ii) In **Coelenterates**, as for example in *Hydra* small pieces of body containing both the germinal layers (1/100th part of the body) regenerate into new organisms. As a matter of fact regeneration was first discovered in *Hydra* by TREMBLY (1740).

Earthworms and several other annelids are able to regenerate some segments removed from the anterior and posterior ends of the body. Some **molluscs** (gastropods) can regenerate only the eyes, eye stalks, parts of head or foot but not the complete of head, while **squids** can also regenerate their arms. Many **arthropods** (insects, crustaceans) can regenerate limbs only. **Starfishes** and several other **echinoderms** are able to regenerate their arms and parts of the disc, while holothurians can regenerate their entire viscera.

Echinoderms exhibit phenomenon of **autotomy.** If an arm of starfish is wounded or roughly handled, it detaches from its base of its own (self amputation). Similarly, at the time of danger, holothurians eject all the internal organs. The lost parts are then regenerated quickly. This phenomenon is called **autotomy.**

Regeneration in Vertebrates

Among **vertebrates**, the regeneration power is well marked in **Urodel Amphibians**, like salamanders, newts and their larvae. These can regenerate
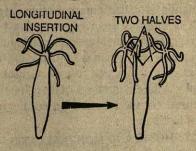
Fig. 27.3   Regeneration in *Hydra*.

limbs, tail, external gills and even jaws, parts of eye (like lens and retina). Tail and limb-regeneration is found in the larval stages of frogs and toads (anuran amphibians). The limb regeneration is absent in adult anurans. Tail regeneration also occurs in **ammocoete larva of lampreys** and in some **lizards.** Lizards also exhibit the phenomenon of
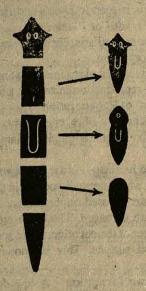
Fig. 27.4   Regeneration in *Planaria* (flatworm).

autotomy. Regeneration capacity is very limited in birds and fishes and is restricted to parts of beak and fins.

In **mammals** the fecundity of regeneration is

restricted to tissues only and is equivalent to wound healing. External parts are not regenerated. The skin and skeletal tissues possess great power of regeneration. Even liver and spleen proliferate to compensate lost parts. Similarly, if one kidney is damaged or removed, the other enlarges to compensate the lost kidney. This type of reparative regeneration is called **compensatory hypertrophy**. It is different from **regeneration** because, while regeneration involves replacement of a lost part by a new one, which is similar to the lost part in structure and function, the compensatory hypertrophy is the enlargement of the counter part to compensate for the function but not the replacement of lost part.

EPIMORPHOSIS AND MORPHALLAXIS

The replacement of lost part of the body by growth and differentiation of cells from the remainder piece of that part is known as **epimorphosis or epimorphic regeneration**. While **morphallaxis or morphallactic regeneration** is the regeneration of new individuals from pieces, isolated fragments or isolated cells of an animal body. It involves reorganization of various parts of an organism from few cells to form a complete individual. This is seen in *Hydra* and *Planaria* (flatworm). If *Hydra* or *Planaria* is cut transversely into two or several arts, each part develops into a complete organism.

Fragmentation and regeneration are usual forms of asexual reproduction in several animals –

Mechanism of Regeneration

The mechanism of regeneration can be studied from limb regeneration in salamander. This involves :

1. **Wound healing** - As a result of amputation the tissues which normally occurs in the interior of limb, are exposed on the surface and some of them are damaged. The epidermal cells from the edges of the cut migrate and spread over the exposed surface. This is known as **wound healing**.

2. **Blastema formation** - A few days after the healing of the cut, the undifferentiated mesenchyme cells accumulate inside the epidermis. Due to this cellular aggregation, a stumpy outgrowth or bulge is formed. This is known as

regeneration bud or blastema. It has the same general properties as exhibited by the limb bud formed in the endorys during link development. The undifferentiated mesenchyme cells resemble the embryonic mesenchyme cells and develop from the differentiated tissues of the stump adjoining the cut surface by the process of dedifferentiation or disintegration. The mesenchyme cells divide rapidly, so that the blastema continues to grow in size for sometime till the differentiation sets in.

3. **Redifferentiation and Morphogenesis** - The blastema now appears as a flattened cone due to dorsoventral flattening. Its flattened part develops rudiments of digits by indentation at the free edge. These grow out into new digits. During this process the undifferentiated blastema cells get differentiated in conformity with the differentiated tissue cells of the limb stump (bone, muscles, blood vessel etc.). This process is known as **redifferentiation**.

4. **Growth** - The regenerated limb increases till it attains the size of a normal limb.

In **Planarians** and Hydra, there are undifferentiated cells called **neoblasts** which multiply and then migrate from deeper parts of the body to the cut surface (site of injury).

EMBRYOGENESIS AND REGENERATION

The process of regeneration can be described as a special kind of embryonic development because of the following similarities -

1. In both cases, the unspecialized cells undergo repeated divisions and finally undergo differentiation to form specialized cells.

2. Like embryogenesis, there is mass migration of cells comparable to morphogenetic movements during gastrulation.

3. Cell differentiation occurring in the blastema leading to morphogenesis is comparable to cell interaction and cell differentiation as in developing embryo. This shows that the developmental capacity is retained even in the adult organisms. The differentiated cells can undergo dedifferentiation and then redifferentiation. However, regeneration is regulated by various hormones and the nervous system of the organism, whereas in embryogenesis the regulation of development may be through some other mechanisms.

Polarity in Regeneration

The body segments of Hydra or Planarian body exhibit distinct polarity during regeneration. Their anterior end always regenerates into head and posterior into the tail. This is because at the forward cut surface metabolic rate is higher than at the rear end.

SENESCENCE AND AGEING

Unicellular organisms (microorganisms and protozoans) are potentially immortal, while in multicellular organisms, except the germ-line cells, the somatic cells show a gradual decline in their functional efficiency. With the advancing age, these become senescent and ultimately die. These dead cells are replaced by new ones by the process of division and differentiation of existing undifferentiated cells. Till the turnover of newly developed cells exceeds the number of dead cells, the multicellular organism grows in size. As the organism grows older, its power of metabolism gradually declines leading to progressive decrease in the production rate of new cells. This means that all the worn out cells are not replaced and repair of damaged parts is not complete. This may ultimately influence the functioning of such vital organs as liver, kidneys, heart and brain etc. All such changes appearing with advancing age are known as **senescence and ageing** which ultimately lead to the death of organism. The field of developmental biology that is associated with the studies of ageing is known as **gerontology**.

Definition of Agening

Ageing, can be defined as **the progressive deterioration in the structure and functions of the cells, tissues, organs and organ systems of the organism with the advancing age.**

Pace of Ageing

The effects of ageing vary widely in different groups. Bacteria, viruses and majority of protozoans are free from ageing. However, none of the multicellular organisms lives for ever. Even under most favourable conditions (with no accident or disease) every metazoan dies its natural death, though the life span differs widely. While some live only for short periods, others may live for several decades or even centuries. Some sea anemones are known to have lived for about 78 years, turtles survive upto 150 years. Many fishes and reptiles are able to inhibit ageing by continuously growing through out their life. Some bristle cone pines of eastern California are over 400 years old.

Even different types of cells have different longevity. In general, cells that differentiate and stop dividing appear to be subjected to changes of ageing than those that are capable of dividing throughout life. Nerve and muscle cells that have lost capacity for cell division undergo ageing at a very slow pace but age at an early age ; whereas tissues like liver, spleen and epidermis which retain capacity of cell division age later but faster.

Symptoms of Ageing

Symptoms of ageing can be treated at three different levels-at organismic level, at cellular level and at extracellular level.

Symptoms of Ageing at Organismic level. Some of the important symptoms of old age in man are –

1. **Heart** - With increasing age the efficiency of heart decreases. In a man of 70 years, the heart pumps only 65 per cent blood per minute as compared to a 30 years old man. Consequently, the blood going to the brain and kidney is reduced to 80 per cent and 42 per cent respectively.

2. **Oxygen uptake by blood** - At the age of 20 blood takes about 4 litres of oxygen per minute, while in a man of 75 years, it takes only about 1.5 litres of oxygen in the same period.

3. **Decrease of blood volume** - The production of new RBCs from the bone marrow declines and consequently the volume of blood also decreases.

4. **Kidney** - The number of kidney tubules is found to reduce to half in the old age. As a result the volume of urine decreases. This creates lots of other urinary troubles and also causes body ache, low back pain and difficulty in passing urine.

5. **Lungs** - The capacity of lungs for intake of air decreases. This leads to reduction in the oxygen supply to different tissues. Therefore, old persons suffer from breathlessness and inflammation of mucous membrane.

6. **Digestive system** - The number of taste buds on tongue reduces to about one third. The secre-

tion of digestive juices also decreases with old age. This may result in indigestion, loss of apetite, dyspepsia, constipation and gas formation.

7. **Retention of water** - The capacity of body cells to retain water also decreases. With the result, the skin in old persons is dry and wrinkled.

8. **Nerve impulse** - The rate of nerve impulse propagation reduces with age. The decline is about ten percent in a man of 75 years as compared to that of 50 years old person.

Table : 27.2: Showing Decline in Structure and Physiological processes in man with Ageing.

(The figures represent percentage of given function in man at the age of 75 as compared to age 50)

S. No.	Structural elements	Percentage
1	Body weight in males	12%
2.	Weight of brain	44%
3.	Number of taste buds	64%
4.	Number of renal glomeruli	44%
5.	Axons in spinal nerves	37%
	Rate of physiological process	
6.	Output of heart at rest	30%
7.	Blood supply to brain	20%
8.	Vital capacity of lungs	44%
9.	Maximum oxygen uptake during exercise	60%
10.	Velocity of nerve impulse	10%
11.	Glomerular filtration rate	31%
12.	Strength of hand-grip	45%
13.	Speed of return to normal pH of blood	83%

I. Cellular Changes

The above discussed and other outwards signs of ageing are the result of changes taking place at cellular, subcellular or extracellular levels. Some of the cellular changes associated with ageing phenomenon are being mentioned here-

1. Morphological Changes

(1) **Accumulation of exhaustion pigment.** The exhaustion pigment-lipofuscin, yellow pigment and brown deposits are by products of unsaturated lipid oxidation. It is especially obvious in nerve and heart muscle cells but is present in almost all other cells of the body, though to a lesser degree. The accumulation of this pigment represents the failure of some excretory mechanism and has important implications in cellular senescence.

(2) **Appearance of lipid vacuoles**-Small lipid vacuoles appears in the cytoplasms.

(3) **Decline in cell volume**-The cells showing ageing exhibit hypotrophy or decrease in cell volume.

(4) **Nuclear pyknosis**-With advancing age, the nucleus becomes shrunken and strains deeply. Such a nucleus is called **pyknotic** and the denegerative process is known as **nuclear pyknosis.** This is caused by the condensation of the nuclear material rather than an increase in chromatin.

2. Physiological Changes

(1) **Accumulation of calcium**-With age Ca^+ ions accumulate in the peripheral cytoplasm due to changes in the permeability of cell membranes.

(2) **Accumulation of collagen**-The collagen protein constitutes upto 30 percent of body weight in many animals. Young collagen is permeable, flexible and easily soluble. With advancing age collagen becomes more abundant, more brittle and shows colour changes of a characteristic nature. Due to these changes it becomes increasingly difficult for oxygen and nutrients to diffuse into the cells and for carbon-dioxide and nitrogenous wastes to pass out. Thus this mechanical obstruction causes deterioration and ageing of cells of various tissues and organs.

(3) Other biochemical changes associated with ageing are - (i) increase in cholesterol levels, (ii) increase in blood globulin, (iii) decrease in alkaline and acid phosphatases and (iv) decrease in cellular respiration.

II. Subcellular Changes

(1) **Plasma membrane**-The permeability of plasma membrane gradually decreases most probably due to accumulation of calcium in the cellular membranes due to ageing process.

(2) **Endoplasmic reticulum** - The amount of granular endoplasmic reticulum decreases in the cytoplasm of old cells. The decrease of Nissl's granules has been recorded in the nerve cells of older animals and man.

(3) **Mitochondria** - Mitochondria become degenerated in the cells of old tissues reducing rate of carbohydrate metabolism and rate of respiration.

(4) **Lysosomes** - Due to autoxidation of lipid com-

ponents of lysosome, **lipofuscin** pigment accumulates in the cell cytoplasm in large amount, especially in cells of brain and muscles. The pigment represents the remains of worn out cell organelle. SHOCK (1962) and SIREHLER (1962-63) have reported the accumulation of Ca+ and other inert matter in aged cells.

(5) **Nucleus** - MINOT (1971) has suggested that it is the change in nucleo-cytoplasmic ratio which acts as an important index for natural senescence and death. With ageing, there is accumulation of chromosomal aberrations and gene mutation which disturb normal functioning of DNA. It has been noticed that the enzyme **aldolase** in the liver cells of mice becomes increasingly inactive with ageing.

III. Extracellular Changes

Inter cellular spaces in all tissues are filled with various materials secreted by the cells, such as polysaccharides, fibrous proteins etc. Collagen protein fibres constitute about 40% of the total protein deposition and as discussed earlier it influences the permeability of cell membranes, affects the speed of diffusion of substances in and out and significantly influence the process of ageing.

Theories of Senescence and Ageing

Cell senescence and resulting organismic senescence leading to old age and death have fascinated both scientists as well as common man. Though much work has been done in this field, still we do not know enough about the process of ageing. Many theories have been proposed to explain the phenomenon of ageing.

1. Environmental Theory of Ageing

Some biologists believe that ageing is largely due to adverse changes in the environment, especially radiations (cosmic rays, X-rays etc.) which induce gene mutations in the somatic cells by errors in DNA duplication. These mutations accumulate and result in the synthesis of defective polypeptide chains and defective proteins. Consequently, this reduces cellular efficiency and results in ageing.

The view is supported by observations on ageing human cells, which produce defective enzymes. Moreover, sublethal exposure of individuals to radiation lowers their life expectancy.

2. Gene Theory of Ageing

According to this theory, all individuals possess **ageing genes** in their genome, which determine the rate of ageing and the maximum life span. There is good deal of evidence to support this view: *(i)* the annual plants age despite the most suitable environmental conditions, *(ii)* different life spans even in different species of mammals, *(iii)* the longevity varies even in different family lines of a single species. B. PAL (1975) has described this phenomenon as **'genetic clock'** or **'genetic time-table'**.

3. Interaction of Heredity and Environment

It is believed that ageing is the result of interaction between hereditary factors and the environment.

4. Theory of Metabolic Rate for Ageing

According to this theory organisms with high rate of metabolism age more rapidly than those with a relatively lower rate of metabolic activities. For example, small mammals like rat and mice which attain maturity in only few weeks after birth, age more rapidly than mammals like man which take years to mature. Similarly birds and insect which have a very high BMR have a very short life span. Even those cells that are more active metabolically, show early signs of senescence and ageing.

5. Cross Linkage Theory

According to this theory ageing is caused by the increase of bonds between protein and nucleic acid molecules in the cell. These bonds alter the functional characteristic of these important cellular components leading to nonavailability of certain functional proteins and resulting in mal functioning of the cell.

6. Waste Product Theory

The accumulation of waste products are considered to poison the cell gradually, resulting in their ageing and death.

7. Diffusion Theory

This theory considers that large molecules may be produced as a result of metabolism at a rate faster than that at which these can be removed from the cell resulting in their accumulation in the cell cytoplasm. Accumulation of collagen fibres may influence the permeability of plasma membrane affecting the speed of diffusion of substances. The

increase in concentration of these molecules results in cell death.

8. Error Catastrophe Theory

ORGEL (1963) suggested that errors in reading the genetic code result in the accumulation of errors in the sequence of amino acids in proteins. If these errors are incorporated in the enzymes required for protein synthesis, will result in further mistakes in synthesis of structural proteins leading to cell senescence or cell death. HOLIDAY (1974) and others have provided evidences in favour of this theory.

They were successful in shortening the life span of adult fruit flies by feeding their larvae on certain amino acid analogues like metheionine and p-flouorophenylalanine. These amino acid analogues substitute methionine and phenylalanine in the protein and interfere with the functions of proteins. HOLIDAY also succeeded in detecting abnormal forms of enzymes in ageing fibroblast. However, certain scientists believe that the errors are not the results of blind chance but are programmed by the ageing genes of the organism.

9. Stress Theory

This theory states that the every day wear and tear on the body and its cells could lead to irreversible damage, finally resulting in death. The older an organism, the less it can withstand stress.

10. Pace Maker Theory of Ageing

The pace maker theory emphasize that there is progressive break down in the immunological system with increasing break down in the immunological system with increasing age. The activity of β-cells (bone narrow derived) and T-cells (thymus derived) decrease in aged animals. On stimulation B-cells differentiate into plasma cells which recrete antibodies. The T-cells from lymphocytes that kill foreign cells. Evidences strongly support the view that the agerelated decline in the immunological activities of the body is largely due to changes in the environment. Two views persist. One school of scientists believes that thymus acts as a pace maker, while others believe that biological clock lies in the brain.

(1) **Thymus as pacemaker**-BURNET has suggested that thymus gland acts as a pacemaker for whole body. Its atrophy is a programmed event. Its disappearance reduces defence mechanism of body against invasion of germs which damage and destroy the tissues.

(2) **Brain as pacemaker**-FINCH suggested that the brain or the central nervous system is the biological clock for determining the senescence and age of animals. It stimulates and regulates the activity of endocrine glands. In absence of any information from brain endocrine glands do not function normally, reducing the hormone level. This leads to defective functioning of cells to ageing.

11. Integrated Theory

This theory has been woven from all above hypotheses, none of which appears to be entirely satisfactory in explaining cell aging. The intergrated theory believes that cross linking in all types of molecules both collagenous and non-collagenous is the major factor in ageing. The cross-linkage rate depends on metabolic rate, the concentration of free radicals and the stress applied to the cells and the organism.

The cross-linking of molecules can affect the cells and the organism by both genetic and nongenetic mechanisms. For example, cross-linking of DNA produces mutations. The mutated DNA will produce proteins of different nature which may prevent the formation of some needed proteins. The cross-linking may involve interactions between collagen and other molecules that form nonfunctional biomolecules. Many large molecules formed in this fashion may diffuse too slowly for elimination and may prove harmful to the cell. Thus waste products and toxic substances would tend to accumulate. Increase in the metabolic rate would tend to speed up the formation of free radicals promoting further cross linking.

Moreover, the integrated system also considers the organism as a total system in which changes in one part of the system drastically affect operations in other parts of the system. For example, the collagen linkages cause a shrinkage of the tissues that surround capillaries. This decreases the supply of nutrients and oxygen to those tissues which, in turn, leads to damage and stress to the tissues.

All the theories discussed above are unsatisfactory in that they do not point out specifically why cellular ageing takes place. These, however, summarise the types of changes associated with ageing.

12. Reconciliation of Theories of Ageing

B.L. STREHLER postulated that the ageing is

programmed by the action of 'on-off switches' that reside in the genetic machinery. The mechanism activates first one set of genes, then another to produce special products (the enzymes, hormones, antibodies etc.) as the individual matures, ages and dies. The specific off switch prevents the key body cells found in the thymus, brain, heart and endocrine glands from dividing once the animal has attained maturity.

Thus, there are too many theories to explain the phenomenon of ageing. Each theory explains a particular aspect of ageing. It is long way to formulate comprehensive theory for explaining different aspects of ageing in all kinds of cells and organisms.

DEATH

Death is a biological event and an essential step in the life cycle of all living organisms. Death occurs due to permanent breakdown or inefficiency in the body functioning. The cells cease to perform normal function.

Causes of death are many. These can be separated into following main categories.

1. **Weakening of tissues** of vital organs such as heart, liver, kidney. This causes physiological metabolic disorders of irreversible nature leading to death.
2. **Sudden blockage** in the circulation of blood to heart lungs and brain. This causes instantaneous death.
3. **Break down of immune system and loss of resistance** either due to old age or due to weakness make persons vulnerably susceptible to infections diseases.

Death is an essential biological phenomenon. It maintains balance in nature.

QUESTIONS

1. Define the term 'growth'. Discuss its significance.
2. What is the basic difference in embryonic and postembryonic phases of life cycle?
3. Explain various types of growths met within animals.
4. Describe hormonal control of growth in human beings.
5. Cell division occurs during embryogenesis but there is insignificant change in the size of embryo upto blastula stage. Why?
6. Differentiate between
   (i) Growth and degrowth
   (ii) Auxetic and multiplicative growth
   (iii) Protoplasmic and apoplasmatic substances.
7. Describe sigmoid curve of growth and explain its significance.
8. Give a schematic account of mechanism of regeneration of salamander limb.
9. Summarise the regenerative capacity in various animal groups.
10. Differentiate between physiological and reparative regeneration.
11. What do you understand by epimorphosis and morphallaxis?
12. How can you justify the statement that regeneration is specialized embryogenesis?
13. Comment on the statement that regeneration declines with age in higher vertebrates.
14. 'Regeneration is a means of reproduction in source animals'. illustrate with examples.
15. What is the basic difference between compensatory hypertrophy and reparative regeneration ?
16. Define the following terms-
    (i) Regeneration.
    (ii) Blastema
    (iii) Compensatory hypertrophy
    (iv) Autotomy
    (v) Epimorphosis
    (vi) Reparative regeneration
17. Define ageing. What are the symptoms of ageing in man?
18. Discuss in brief the cellular and extracellular changes that occur during the process of ageing.
19. Describe briefly various theories of ageing.
20. Name various theories of ageing and describe the one which you consider to be most appropriate.
21. Describe the role of thymus gland in the process of ageing.
22. In what way does the brain influence ageing in animals?
23. Illustrate with two examples the correlation that exists between speed of ageing and rate of metabolism.
24. Explain the role of collagen fibres in process of ageing.
25. Mention the cellular changes that occur during ageing.
26. Why are micro-organisms called potential immortals ? Explain.

27. How does continuous growth avoid ageing ?
28. What will happen if a group of mice is exposed to sublethal dose of X-ray radiation?
29. What will be the effect on ageing if a population of *Drosophila* is fed with amino-acid analogues like metheionine, p-fluorophenyl alanine as a substitute to methionine and phenylalanine ?
30. Mention the evidences in support of gene theory of ageing.
31. Define ageing and gerontology.
32. Name the branch of developmental biology that deals with ageing.
33. Name those groups of animals which do not age and which age early.
34. Which cells age early-brain cells or liver cells and why ?
35. What do you mean by natural death ?
36. Mention the effect of old age on heart and kidney.
37. What is the speed of nerve propogation in an old man of 70 years ?
38. Name the oldest living plant on this earth.

□ □

CHAPTER 28

Heredity and Variations

INTRODUCTION

'Like begets like' is a long known phenomenon and explains that living things tend to produce offsprings that resemble them. Children tend to resemble their parents, grandparents and grand - grand parents. You must have heard casual remarks as 'he is carbon-copy of his father' or 'he has fathers nose or grandfather's eyes or she has mother's complexion. The ancient Greeks knew that blue eyed parents have blue eyed children ; that baldness and squint eyes follow in successive generations ; that certain eye defects run in particular families. This passage of characters from one generation to next is called **inheritance** or **heredity.**

HEREDITY AND VARIATIONS

Heredity may be defined as *the transmission of characters in living beings from one generation to successive generations.* It can be described as genetic continuity of germinal material between parents and offsprings. It deals with the occurrence and inheritance of physical and physiological characteristics, instincts and even psychological features in higher animals and men.

Genetics *is that branch of biological Sciences which deals with the mechanism of transmission of characters from parents to offsprings.*

Though the offsprings resemble their parents, they are not identical. They usually differ among themselves and also from their parents. Except for identical twins, no two siblings or brothers and sisters show close resemblance. Differences among individuals of a species are called **variations.**

Variations are of two types :
1. **Environmental Variations** are due to food, temperature or other external factors.
2. **Hereditary variations** are due to genetic or genic difference.

The science of **genetics** seeks to account for the resemblances and differences due to heredity, their source and their development.

A. Heredity and variations in Forms with Sexual Reproduction

Sexual **reproduction** **introduces** **heterozygosity** in the populations of living beings, because at the time of fertilization, the two hereditary streams are brought together by the fusion of ovum and sperm from female and male parents respectively. This leads to genetic variations in the offsprings. **Inbreeding** (mating in closely related organisms) tends to establish **homozygosity** and reduces variations.

B. Heredity and Variations in forms with Asexual Reproduction

In **asexual reproduction**, the offsprings arise from the single parent without the formation and fusion of male and female gametes. So these are carbon copy of the parent and are called its **clone.** Sexual reproduction occurs among the members of same species, because interspecific hybrids are sexually sterile.

Interspecific hybrids in animals are infertile *e.g.* **mule** (a hybrid between a mare and donkey). In plants, sterile interspecific and intergeneric hybrids can be propagated by vegetative propagation. Some such infertile plant hybrids can be made fertile by doubling their chromosome number. Such fertile hybrids with doubled chromosome numbers form new species. The chromosome number can be **doubled by treating cells with colchicine,** a drug which inhibits **mitosis** after anaphase.

Clone

Presently the term **offsprings** is strictly used for the progeny produced by sexual reproduction. Progeny produced asexually by budding, fission, spore formation or grafting and layering (in plants) forms a **clone**.

It means **clones** have identical genetic make up. **Identical twins** are also clone to each other, though they are offsprings to their parents. These exhibit little or no variation as compared to sexually produced offsprings. The variations if any, in clones are not genetic but arise due to influence of the environment and are nonheritable. Heritable changes

in clones arise by mutations in their hereditary material (gene mutations and chromosomal mutations).

Budding, grafting, layering, cutting etc. are common methods of vegetative propagation. Recently developed technology of tissue culture has further helped scientists in clonal propagation.

Clonal propagation of perennial plants has helped horticulturists, gardeners and plant breeders in the multiplication of desired species of plants and restoring their genotypes in cases :

1. When crop may not produce seeds (sterile hybrids).
2. When multiplication through seeds produces wide variation and the progeny may not breed true to the parental types.
3. Conditions may not be favourable for seed sowing.

HISTORY

Genetics, is barely three-quarters of a century old. The first marked pioneer and experimental work in this field was started by GREGOR JOHANN MENDEL (1822 - 1884), but it was established as a distinct branch in 1900, when Mendel's findings were rediscovered by DEVRIES, CORRENS and TSCHERMAK.

PreMendelian Work

Though breeding experiments for the improvement of races of domesticated plants and animals were conducted by Babylonians and Assyrians thousands of years before the Christian Era, it was not known what exactly is passed on from parent to offsprings to make them similar or different.

1. **Vapour and Fluid Theory** - Early Greek philosopher PYTHAGORAS (500 B.C.) proposed that some moist vapour is given out from brain, nerves and other parts of body of male during coitus that makes the offspring resemble male parent.
2. **Semen Theory** - EMPEDOCLES suggested that both parents produce semen that arises from its various body parts. The semen from both parents mixes to produce the new individual.
3. **Particulate Theory** - French biologist MAUPERTUIS (1989-1795) proposed that the body of each parent gives rise to minute particles. In sexual reproduction, these particles from both the parents blend together

to form the daughter individual.
4. **Pangenesis Theory** - CHARLES DARWIN proposed that every cell, tissue and organ of animal body produces many minute particles known as gemmules or pangenes. These are discharged in the blood stream and are deposited in the reproductive organs. The reproductive cells contain these pangenes and a offspring develops as a result of blending of pangenes from two parents.

Blending Inheritance

Thus scientists of preMendelian era believed in blending inheritance that the qualities of two parents get blended or mixed up in the offsprings, which exhibit some intermediate results. However, this concept is not acceptable now due to a multifarious increase in the field of Genetics.

The parental characters do not blend in the offsprings. These remain discrete and may reappear after several generations. German botanist KOLREUTER presented experimental evidence to show that characters remain discrete.

MENDEL

The Austrian monk GREGOR JOHANN MENDEL was first to explain the mechanism involved in the transmission of characters from parents to the offsprings generation after generation. He is, there-

Fig. 28.1 Mendel (1822-1884) •

fore, considered to be pioneer of modern genetics and is called "Father of genetics".

MENDEL was born in a gardener's family and received his early education in the village. In October 1843, MENDEL entered Augustinian monastery at Brünn in Austria as a priest. There, in spare time, he conducted his historic experiments with garden

pea (*Pisum sativum*) in the monastery garden for about nine years from 1856 to 1864. The results of these classical experiments and Mendel's conclusion were published in an obscured journal - *The Annual Proceedings of the Natural History Society of Brunn* in 1865. Unfortunately, his outstanding contributions were overlooked by the scientific world of that time and remained obscured till in 1900 these were rediscovered by three different scientists from three different corners of Europe, while working independently on heredity in plants. These were HUGO DEVRIES from Holland, KARL CORRENS from Germany and ERIC VON TSCHERMAK from Austria.

MENDEL'S EXPERIMENT

MENDEL conducted cross breeding experiments on garden pea (*Pisum sativum*). He studied the inheritance of seven different pairs of contrasting characters in this plant but considered only one pair at a time. He crossed two pea plants with alternate characters by **artificial pollination**. The resulting hybrids were then crossed with each other. He pooled data of many similar crosses and analysed the results very carefully.

Reasons for Mendel's Sucess

A combination of luck, foresight, mathematical background and scientific aptitude contributed to the success of Mendel's experiments.

A. Method of Working

(*i*)   MENDEL studied the **inheritance of one character at a time**. His method of study differed from his predecessors who had considered the organism as a whole.

(*ii*) MENDEL carried out experiments to F_2 and

F_3 generations.

(*iii*) He maintained the statistical records of all the experiments and analysed them carefully.

(*iv*) He selected the parent plants that were genetically pure (pure breed) or (pure line). It was ascertained that by a series of self crossing tests between progeny of each successive generation.

(*v*)   Crossings were done between the parents of pure lines having sharply visible contrasting characters.

(*vi*) He grew pure lines in separate garden plots, preventing chances of their mingling with others.

B. Selection of Material

MENDEL selected garden pea as his experimental material, because it has the following advantages :-

(*i*)   It was an annual plant. Its short life-cycle made it possible to study several generations within a short period.

(*ii*) It has perfect bisexual flowers containing both male and female parts. The flowers are predominantly self-pollinating.

(*iii*) Its petals completely enclose the reproductive organs until fertilization, thereby ensuring self pollination.

(*iv*) It is easy to cross because pollens from one plant can be introduced to the stigma of another plant by removing anthers.

(*v*)   Because of self fertilization, plants are homozygous. It is, therefore, easy to get pure lines for several generations.

(*vi*) The pea plants show a number of contrasting characters.

Table 28.1. List of Seven Pairs of Contrasting Characters in Pea Plant

	Character	Dominant	Recessive
1.	Stem length	Tall	Dwarf
2.	Flower Position	Axial	Terminal
3.	Pod shape	Inflated	Constricted
4.	Pod colour	Green	Yellow
5.	Seed shape	Round	Wrinkled
6.	Seed colour	Yellow	Green
7.	Seed coat colour	Grey	White

C. Selection of Traits

MENDEL selected seven pairs of contrasting characters and luckily all related as dominant and recessive. These seven pairs of contrasting characters are shown in the table- 28.1 on previous page.

D. Crossing Techniques

Since garden pea is self-pollinating, a great care was taken during the experiments-

(i) To prevent the possibility of self-fertilization, the anthers were removed from the plants taken as seed parents, even before the stigma was fully mature.

(ii) The pollen from the pollen parent was transferred at the dehiscence stage and was dusted on the feathery stigma of those flowers from which anthers were removed.

(iii) These cross pollinated flowers were enclosed in separate bags to avoid further deposition of pollens from some other source.

(iv) Seeds were collected separately in marked bottles. In case of seeds character, seeds were studied immediately but for other plant characters, seeds were sown to raise the plants and the pod character, flower characters and stem characters were noted.

(v) Even the reciprocal crosses were conducted but no change was observed in the expected ratio of offsprings.

The plants used as parents are said to represent **parental generation**, designated by (P_1). The progeny obtained as a result of crossing between parents is called **first filial generation**, represented by F_1 (The word *filial* means offsprings). The progeny obtained as a result of self-fertilization among F_1 plants represents **second filial generation** (F_2 generation).

MONOHYBRID CROSS

(Experiments with Garden Pea for Single Pair of Contrasting Characters)

Procedure - MENDEL allowed pea to self-pollinate for several generations. He found that the seven pairs of contrasting characters he had identified were always handed down from parent to offspring. Seeds from tall plants produced only tall plants, and yellow seeds produced plants which always yielded yellow seeds. Then MENDEL decided to cross two plants with contrasting traits. Se-

lecting tall (about 6') and dwarf plants (about 1'), he made hundreds of crosses by transferring the pollen from tall to the stigma of dwarf plants. When the seeds matured on the short plants, he sowed them and found that all the plants were tall like the plants from which pollen was used for fertilization.

The plants of this generation belonged to F_1 generation. These F_1 tall plants were allowed to self-pollinate. he seeds were again collected and sown. The plants raised were said to belong to second filial generation (F_2). Surprisingly, plants of F_2 generation were both tall and dwarf, which exhibited an approximate ratio 3 : 1. The dwarf plants of F_2 were found to produce only dwarf plants generation after generation, whether these were self-pollinated or cross pollinated among themselves. Of the tall plants of F_2 only 2/3rd were found to breed true for tallness. The rest 2/3rd produced tall and dwarf in the ratio of 3 : 1 (F_3 generation). It means F_2 generation consisted of three types of plants (instead of apparent two
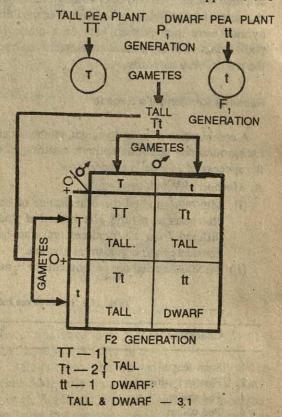
Fig. 28.2 . Mendel's explanation of monohybrid cross between tall and dwarf pea plants.

types) –

1. Tall homozygous (pure)   25%
2. Tall heterozygous   50%
3. Dwarf homozygous (pure)   25%

Mendel's Explanation and Interpretation

MENDEL explained above results by presuming that-

(a) **Tallness** and **dwarfness** are determined by a pair of contrasting **factors or determiners** (now these are called genes). A plant is tall because it possesses determiners for tallness (represented by T) and a plant is dwarf because it has determiners for dwarfness (represented by **t** or **d**).

(b) These determiners occur in pairs. One member of this pair is contributed by each parent.

(c) When two factors for alternative expression of a trait are brought together by fertilization, only one (the **dominant trait** - tallness) expresses itself masking the expression of other (the **recessive trait** - dwarfness). On the basis of this behaviour the tallness is described as **dominant character** and dwarfness as **recessive** (law of dominance and recessiveness).

(d) The determiners are never contaminated but when gametes are formed, these unit factors segre-gate so that each gamete gets only one of the two alternative factors. It means factors for tallness (T) and dwarfness (t) are separate entities and in a gamete either **T** or **t** is present. When F₁ hybrids (Tt) are self pollinated the two entities separate out and unite independently producing tall and dwarf plants (law of segregation)

Example of Monohybrid Cross in Animals

Coat colour in Guinea Pig - When a homozygous black guinea pig is crossed with a homozygous white guinea pig, all the F₁ offsprings are found to be black. It means black colour is dominant to the white colour in guinea pigs and F₁ black offsprings are heterozygous. If gene for black colour is represented by B and for recessive white colour by b, the black guinea pigs of P₁ will be BB and white bb. When crossed, the heterozygous hybrid of F₁ will be Bb. When these F₁ hybrids produced ova and sperms, 50% of the ova will carry gene B for blackness and 50% will carry the gene b for white. The same will be true for the sperms. Their union will result in 25% homozygous black (BB), 50% heterozygous black (Bb) and 25% homozygous white, *i.e.* black and white in the ratio of 3 : 1
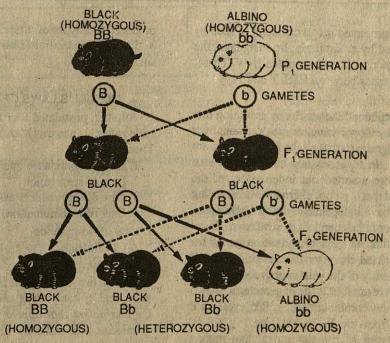
Fig. 28.3: Inheritance of coat colour in guinea pig.

DIHYBRID CROSS

(Cross Involving Two Pairs of Contrasting Characters)

Procedure

MENDEL conducted experiments to study the segregation and transmission of two pairs of contrasting characters at a time. He studied the inheritance of round and wrinkled characters of seed coat along with the yellow or green colour of seeds. MENDEL found that a cross between round yellow and wrinkled green seeds (P_1) produced only round and yellow seeds in F_1 generation, but in F_2 four types of combinations were observed. Two of these combinations were similar to the parental combination, while the other two were new combinations. These are :
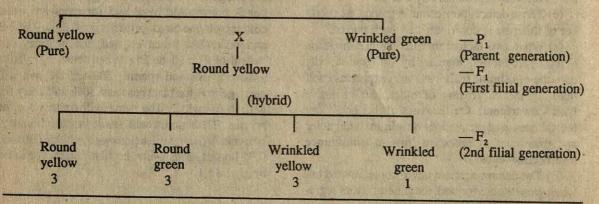
(i) Round yellow	9	Parental combination
(ii) Round green	3	
(iii) Wrinkled yellow	3	} New combinations
(iv) Wrinkled green	1	Parental combination

Thus the offsprings of F_2 generation were produced in the ratio of 9 : 3 : 3: 1. This ratio is called **dihybrid ratio.**

The results can be represented as follows -

Round yellow (Pure)	X	Wrinkled green (Pure)	— P_1 (Parent generation)
	Round yellow		— F_1 (First filial generation)
	(hybrid)		

Round yellow	Round green	Wrinkled yellow	Wrinkled green	— F_2 (2nd filial generation)
3	3	3	1	

MENDEL represented round character of seed by R and wrinkled by r. Similarly, he designated the yellow character by Y and wrinkled by y. Therefore, it was a cross between **RRYY** and **rryy.**

Explanation

MENDEL explained the results by assuming that the round and yellow characters are dominant over wrinkled and green so that all the F_1 offsprings are round yellow. In F_2 generation since all the four characters were assorted out independent of the others, he said that a pair of alternate or contrasting characters behave independently of the other pair, i.e. seed colour is independent of seed coat. Therefore, at the time of gamete formation genes for round or wrinkled character of seed coat assorted out independently of the yellow or green colour of the seed. As a result four types of gametes with two old and two new combinations, i.e. **RY, ry, Ry, rY** are formed from the F_1 hybrid (see Fig. 28.4). These four types of gametes on random mating produced four types of offsprings in the ratio of 9 : 3 : 3 : 1 in F_2 generation (Law of Independent Assortment).

MENDEL'S LAWS OF INHERITANGE

MENDEL postulated four laws, which are now called after his name as Mendel's laws of heredity. These are -

1. Law of dominance and recessiveness
2. Law of segregation
3. Law of independent assortment
4. Law of recombination.

1. Law of Dominance

(a) **Definition** - The Law of Dominance and Recessiveness States -

"When two homozygous individuals with one or more sets of contrasting characters are crossed, the characters that appear in the F_1 hybrid are **dominant** *and those do not appear in F_1 are* **recessive characters."**

P₁ GENERATION

YELLOW ROUND SEEDS
YYRR

GREEN WRINKLED SEEDS
YY'''

GAMETES ‎ YR ‎ YELLOW WRINKLED SEEDS ‎ Yr

YyRr

F₁ GENERATION

GAMETESO

	YR	yR	yr	yr
YR	YYRR YELLOW ROUND 1	YyRR YELLOW ROUND 2	YYRr YELLOW ROUND 3	YyRr YELLOW ROUND 4
yR	YyRR YELLOW ROUND 5	yyRR GREEN ROUND 6	YyRr YELLOW ROUND 7	yyRr GREEN ROUND 8
Yr	YYRr YELLOW ROUND 9	YyRr YELLOW ROUND 10	yyrr YELLOW WRINKLED 11	Yyrr YELLOW WRINKLED 12
yr	YyRr YELLOW ROUND 13	yyRr GREEN ROUND 14	Yyrr YELLOW WRINKLED 15	YYrr GREEN WRINKLED 16

GAMETES

F₂ GENERATION

YELLOW ROUND : 9 YELLOW WRINKLED : 3
GREEN ROUND : 3 GREEN WRINKLED : 1

Fig. 28.4 Mendel's dihybrid cross between pea plants having yellow round seeded and green wrinkled seeds.

(b) Critical appreciation of Law of Dominance - A large number of cross-breeding experiments conducted by CORRENS, TSCHERMAK, DEVRIES BATESON and his collaborators on a variety of organisms by DAVENPORT on poultry, by HURST on rabbits, have established that a large number of characters in various organisms are related as dominant and recessive. Seven pairs of characters in pea have already been mentioned.

2. Law of Segregation (Purity of Gametes)

(a) **Definition** - The law of segregation states *that when a pair of contrasting factors or genes or allelomorphs are brought together in a heterozygote (hybrid)) the two members of the allelic pair remain together without being contaminated and when gametes are formed from the hybrid, the two separate out from each other and only one enters each gamete.*

Mendel's monohybrid cross between pure tall and pure dwarf pea plants can be used to illustrate the phenomenon of segregation. Pure tall plants are homozygous and, therefore, possess genes (factors) **TT**, similarly dwarf possess genes **tt**. The tallness and dwarfness are two independent but contrasting factors or determiners. Pure tall plants produce gametes all of which possess gene **T** and dwarf plants t type of gametes.

(b) **Critical appreciation of law of segregation** - The law of segregation of genes without their admixture in the hybrid was conception in original but purely theoretical, propagated by MENDEL. It has since been confirmed by cytological studies. Dominance or no dominance, the law of segregation holds good to all cases. Its far reaching applicability has made it a rare biological generalization.

3. Law of Independence Assortment

(a) **Definition** - *If the inheritance of more than one pair of characters (two pairs or more) is studied simultaneously, the factors or genes for each pair of characters assort out independently of the other pairs.* MENDEL formulated this law from the results of a dihybrid cross. The cross was made

between plants having **yellow and round cotyledons** and plants having **green and wrinkled cotyledons.** The F_1 hybrids all had yellow and round seeds. When these F_1 plants were self fertilized they produced four types of plants in the following proportion :

(i) Yellow and round   9
(ii) Yellow and wrinkled   3
(iii) Green and round   3
(iv) Green and wrinkled   1
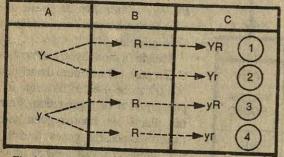
Fig. 28.5 Forked line method showing formation of four types of gametes by a F_1 dihybrid for cotyledon colour and shape of cotyledon.

The above results indicate that yellow and green seeds appear in the ratio of 9+3 : 3+1 = 3 : 1. Similarly, the round and wrinkled seeds appear in the ratio of 9+3 : 3+1 = 12 : 4 or 3 : 1.

(i) gene for yellow colour of cotyledons   **Y**
(ii) gene for green colour for cotyledons   **y**
(iii) gene for round character of cotyledons   **R**
(iv) gene for wrinkled character of cotyledons **r**

Therefore, plants with yellow and round cotyledons will have their genotype **YYRR** and those with green and wrinkled cotyledons will have a genotype **yyrr**. These plants will produce gametes with genes **YR** and **yr** respectively. When these plants are cross pollinated, the union of these gametes will produce F_1 hybrids with **YyRr** genes. When these produce gametes all the four genes have full freedom to assort independently and, therefore, there are possibilities of four combinations in both male and female gametes :

(i) **RY**   (ii) **Ry**   (iii) **rY**   (iv) **ry**

(b) **Critical appreciation of law of Independent Assortment** - The law of independent assortment fails to have a universal applicability. Cytological studies have revealed that only those allelomorphs assort independently during meiosis, which

are located in different homologous pairs. But, if the allelomorphs for different characters are present in the same homologous pair of chromosomes, these are passed on to the same gamete. Law of independent assortment does not apply to such cases.

Biological Importance of Mendelism

Mendel's laws have practical application in plant and animal breeding. With the help of these laws it is possible to produce animals and plants with desired characteristics by cross breeding, hybridization and selected. A variety of disease resistant and high-yielding crops, various new breeds of horses, dogs, hen, *etc.* have been produced. The science of eugenics is the outcome of Mendelism.

SYMBOLS AND TERMINOLOGY

(A) Symbols

1. **Classical Method** - MENDEL used English alphabets to represent the factors. The first letter of the dominant character is often used to designate the character. Its capital letter, as **T** for tallness, represents the dominant character and small letter **t** represents its recessive character (dwarfness).

2. **Modified Classical Method** - Very often the letter is chosen on the basis of mutant character. The mutant character when recessive is designated by small letter and its wild or normal character is represented by the capital letter. For example, albinism in man is recessive mutant. It is represented by 'a' whereas the normal skin colour is represented by 'A'.

3. Another method of using the symbols includes the use of + sign for the wild type and its mutant is represented by the first letter of the mutant character either as capital or small depending upon whether mutant is dominant or recessive. For example, in tall and dwarf characters of pea plants the wild or tall character is represented as +/+ and dwarf as d/d. The genotype of F_1 hybrids will be represented by +/d.

(B) Terminology

1. **Gene** - MENDEL presumed that a character is determined by a pair of **factors** or **determiners** present in each cell of the individual. These are known as **genes** in modern genetics.

2. Genotype and phenotype - The term **genotype,** *designates the genetic make up of an organism, whereas, phenotype is used to indicate the external appearance of an individual.* For example, in F_2 generation of tall and dwarf pea plants, the tall plants have two types of genetic composition. 1/3rd of them are **TT** and the 2/3rd **Tt**. But irrespective of their genetic composition they develop the same tall character. TT and Tt is the genotype of the tall plants, whereas the tall character is their phenotype. These terms were used by JOHANSSEN in 1911.

3. Homozygous and Heterozygous - Every organism possesses two genes for every character. *If in an organism the two genes for a particular character are identical, it is said to be pure* or **homozygous.** The prefix *homo* means 'the same' and *zygo* mean 'a pair'. For example, tall plants with TT or Dwarf plants with tt are homozygous.

Heterozygous *organism possesses contrasting genes of a pair.* It receives two different alleles for the same character from its two parents. The prefix *hetero* means 'different' and *zygo* means 'a pair'. It means an organism with T and t (Tt) will be heterozygous.

4. Allele or Allelomorph - Allele is a Greek word which means 'belonging to one another'. It is used to refer to one member of a gene pair. According to MENDEL two genes representing two alternatives of a character are present on two separate chromosomes but at the corresponding loci. For example, in a gene pair Tt, T is present on one chromosome and t on the other chromosome, each of them is called an allele to other *i.e.* T is an allele to t and vice versa.

5. Dominant and Recessive - A heterozygote possesses two contrasting genes, but only one of the two is able to express itself, while the other remains hidden. *The gene which gains expression in F_1 hybrid is known as* **dominant gene,** while the other gene which is unable to express itself in presence of the dominant gene is the **recessive gene.**

For example, a heterozygous tall plant has one gene for tallness (T) and one for dwarfness (t). The gene for tallness (T) is dominant and the gene for dwarfness (t) is recessive.

6. Monohybrid Cross - It involves the study of inheritance of one pair of contrasting characters. For example, inheritance of tall and dwarf characters or the yellow and green colour of seed cotyledon is monohybrid inheritance.

7. Dihybrid Cross - It involves the study of heritance of two pairs of contrasting characters. For example, the inheritance of yellow and round
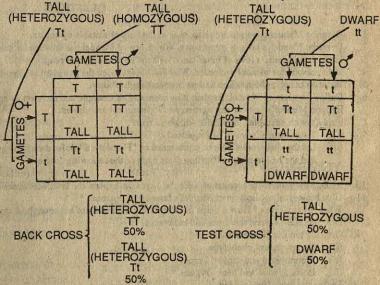
Fig. 28.6. Diagram of back cross and test cross, whereby a heterozygous tall pea plant is differentiated from homozygous tall pea plant.

seed character and the green wrinkled character is a dihybrid inheritance.

8. Polyhybrid Cross - It includes those crosses in which inheritance of more than two pairs of genes is considered.

9. Reciprocal Crosses - The reciprocal crosses involve two crosses concerning the same character but with reversed sexes. It means if in first cross A is used as a female present and B as the male parents, then in the 2nd or reciprocal cross A will be used as male parent and B as female parent.

10. Back cross and Test cross - In Mendelian inheritance the F_2 offsprings are obtained by self-pollination in the F_1 hybrids. But the F_1 hybrids can be crossed with either of the two parents of P_1 generation. Such crosses between offsprings (hy-

brid) and parents are known as **back crosses**. When F_1 offsprings are crossed with the dominant parents all the F_2 offsprings develop dominant character. On the other hand, when F_1 hybrids are crossed with recessive parent, individuals with both the phenotypes appear in equal proportion. While both the crosses are known as **back cross** the second one is specified as **test cross**.

The **test cross** is, therefore, a *cross between heterozygous* F_1 *hybrid and the double recessive homozygous*. The test cross is used to determine whether the individuals exhibiting dominant character are homozygous or heterozygous.

Example - (*a*) Cross between tall heterozygous (F_1 hybrid) with homozygous tall pea plant produces all tall offsprings. But only 50% of them are tall homozygous. The other 50% are heterozygous tall.

(*b*) A cross between tall heterozygous F_1 hybrid with dwarf (homozygous recessive - P_1) produces tall and dwarf in equal proportion indicating that F_1 hybrids are heterozygous.

QUESTIONS

1. Describe Mendel's laws of inheritance with the help of suitable examples.
2. Describe Mendel's laws of inheritance. Which law of Mendel has universal applicability?
3. Formulate Mendel's laws of inheritance with the help of dihybrid ratio.
4. Give reasons for Mendel's success. Why did Mendel used the pea plant as experimental material ?
5. Write an essay on Mendelism and its practical applicability.
6. Define first law of Mendel. Explain it by means of an example and mention its application.
7. Explain Mendel's laws of segregation and independent assortment.
8. Explain with examples 'Mendelian dihybrid ratio'.
9. (*i*) State Mendel's law of segregation.
   (*ii*) Let the allele for tallness be represented by 'T' and the allele for dwarfness by t. What will be gametes produced by the parents and the height of the offsprings from each of the following crosses :
       (a) Tt × tt   (b) TT × Tt   (c) Tt × Tt.
10. Make a diagrammatic account of a dihybrid cross to explain the law of independent assortment.
11. Give biological application of Mendel's laws of inheritance.
12. What is a test cross ? How it helps in interpreting the results of a monohybrid cross?
13. Differentiate between test cross and backcross.
14. Give differences between—
    (*i*) Genotype and phenotype
    (*ii*) Monohybrid and dihybrid cross
    (*iii*) Homozygous and heterozygous.
15. Define the three laws of Mendel.
16. Why Mendel got success, whereas his predeccesors failed to discover the basic principles of inheritance ?
17. Yellow and round peas are crossed with green and wrinkled peas. All the peas in F_1 generation are yellow and round. Work out the phenotype ratio in F_2 generation.
18. Define law of segregation.
19. What is law of purity of gametes ?
20. What do the following genetic symbols mean :
        AA, Aa, aa
21. Name the scientists who rediscovered Mendel's laws.
22. What is pure-line ?
23. What is gene ?
24. Who is considered as 'father of Genetics' ?
25. Define the following terms :
    (*i*) Phenotype   (*ii*) Genotype   (*iii*) Pure-line
    (*iv*) Segregation   (*v*) Dominant   (*vi*) Recessive
26. Coin one word for the following :
    (*a*) A cross of F_1 individual with the homozygous recessive parent.
    (*b*) A group of individuals showing same expression for a character.
    (*c*) A group of plants having same genes for a character.
    (*d*) An individual which does not breed true for its character.
    (*e*) A study of resemblances and difference between the parents and their offsprings.
    (*f*) A group of individuals which produce offsprings for several generations having individual characters.

□ □

Genes and Chromosomes

The term 'gene' was introduced by JOHANNSEN (1909) for Mendelian factors or determiners.Their exact nature and structure was not known at that time.

GENE CONCEPT

The gene concept was introduced by SUTTON. The study of MORGAN, BRIDGES and MULLER etc. elaborated it. The essential features of modern concept of genes are the following :

1. **Genes** determine the physical as well as physiological characteristics. These are transmitted from parents to the offsprings generation after generation.
2. **Genes** are situated in the chromosomes.
3. Since the number of genes in each organism is very large in comparison to the number of chromosomes, several genes are located in each chromosome. In man about 40,000 genes are known to be located on 23 pairs of chromosomes.
4. Each gene occupies a specific position in a specific chromosome. This position is known as **locus** (*pl. loci*).
5. Genes in the chromosomes are arranged in a single linear order like the arrangement of beads on a string.
6. A single gene may occur in several forms or in several functional states. The forms other than normal are known as **alleles.**
7. Only those genes are known which have their alternative alleles.
8. The alleles may be related as **dominant** or **recessive** but not always.
9. Some genes mutate more than once and have **more than two alleles.** These are known as **multiple alleles.** Whatever may be the number of alleles in a multiple series only two of them are found in an individual because of the presence of two homologous chromosomes of each type.
10. The gene may undergo sudden change in expression due to change in its composition. The changed gene is known as **mutant gene** and the phenomenon of change is known as **mutation.**
11. Genes duplicate themselves very accurately. The phenomenon is known as **replication.**
12. Genes express themselves by producing **enzymes** which are proteins. It means each gene synthesizes a particular protein which acts as enzyme and brings about an appropriate change.
13. A gene is a segment of DNA which contains the information for one enzyme or one polypeptide chain coded in the language of nitrogenous bases or the nucleotides. The sequence of nucleotides in a DNA molecule representing one gene determines the sequence of amino acids in the polypeptide chain (the **genetic code**). The sequence of three nucleotides reads for one amino acid (**codon**).

CHROMOSOME THEORY OF HEREDITY

The term **chromosome** (Gr. *chrome*, colour; *soma*, body) when used by WALDEYER in 1888 represented the darkly stained individualized bodies located in the nucleus. WALTER S. SUTTON (1900) after the rediscovery of Mendel's laws, described the parallelism between the segregation of chromosomes during meiosis and the transmission of hereditary factors or determiners (genes) during gametogenesis based on the following facts -

1. Both are found in pairs in diploid cells.
2. Homologous chromosomes separate and gene - pairs segregate during meiosis.
3. Paired condition of both genes and chromosomes is restored during fertilization.
4. The gametes have only one set of genes and of chromosomes.

On the basis of these similarities 'Chromosome Theory of Inheritance' was proposed by SUTTON and BOVERI in 1902 independently.

Its salient features are :

(i) The somatic cells of an organism which develop from the zygote are all **diploid** *i.e.* these consist of two sets of chromosomes. One set of chromosomes is received from

mother (**maternal set**) through ovum and the other set from father through sperm (**paternal set**). The two chromosomes of one type constitute the **homologous chromosome pair**.

(ii) The chromosomes retain their structural uniqueness, individuality and continuity throughout the life-cycle of an organism.

(iii) Each chromosome carries specific determiners or Mendelian factors and plays a significant role in the development of an organism from the zygote.

(iv) The behaviour of chromosomes during meiosis, which occurs at the time of gamete formation provides an evidence that genes or determiners are located in the chromosomes. This also explains the mechanism of segregation and independent assortment of characteristics at the time of gamete formation.
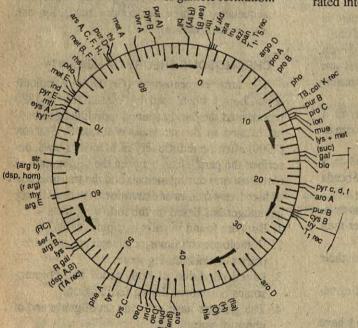
Fig . 29.1   Bacterial chromosome of *Escherichia coli*.

1. PROKARYOTIC GENOME

(a) Baterial chromosome

In bacteria and blue green algae, the hereditary material is organised into a single large circular chromosome composed of a circular molecule of double stranded DNA. It is known as **bacterial chromosome or nucleoid**. It lies free in the cyto-

plasm in the nuclear zone and has no protein around the DNA molecule. However, some RNA is found associated with it and forms backbone or core.

The circular chromosome of *Escherichia coli* has a contour length of about 1,360 μm (1.36 mμ) and is about 23Å broad. Its molecular weight is about 2.8×10^9. It has about 50 or more highly twisted or supercoiled loops and about four million nucleotide pairs.

(b) Plasmid

In addition to the single large circular chromosome, each bacterial cell contains from 1 to 20 much smaller circular duplex DNA molecules, which are called **plasmids**. The plasmids resemble viral DNA in size, ranging from 5 to 100 megadaltons. These replicate in fixed numbers along with the chromosome. Some of them become incorporated into the host cell chromosome and are called **episomes**. These are sometimes transferred from one bacterial cell to another during conjugation and give them new characteristics.

2. EUKARYOTIC GENOME

OR

EUKARYOTIC CHROMOSOMES

In resting nondividing eukaryotic cells the hereditary material or genome is nucleo-protein complex called **chromatin**. It is formed of deoxyribonucleic acid + proteins (DNA + protein). It is amorphous and is randomly dispersed in the nuclear matrix as interwoven network of fine chromatin thread. When cell prepares to divide, the chromatin condenses into a species-specific number of well defined **chromosomes**.

Number

The number of chromosomes in the somatic cells of higher animals and plants is known as **diploid** or **somatic** or **zygotic number**, while in the gametes (sperms and eggs) it is **haploid, gametic** or **reduced**. The number of chromosomes is constant in all the somatic cells of all the individu-

Table 29.1 : Number of Chromosomes in some Eukaryotes

S.No.	Name of Organism	Somatic chromosome Number
	In Animals	
I.	**Invertebrates**	
1.	*Paramecium aurelia*	30-40
2.	*Hydra vulgaris*	92
3.	*Ascaris megalocephala*	2
4.	*Ascaris lumbricoides*	48 in male
5.	*Drosophila melanogaster*	8
6.	Honey bee - male	16 (Haploid)
7.	„ female	32 (Diploid)
8.	Cockroach - male	23
9.	„ female	24
10.	Grasshopper	24
11.	*Culex pipen* (mosquitoes)	6
12.	Silkworm	56
II.	**Vertebrates**	
13.	Frog (*Rana*)	26
14.	*Mus musculus* (mouse)	40
15.	*Rattus rattus* (rat)	42
16.	*Felis domesticus* (cat)	38
17.	*Canis - familiaris* (dog)	78
18.	Cow	60
19.	Horse	64
20.	Monkey	42
21.	Chimpanzee	48
22.	*Homo sapiens*	46
	In Plants	
1.	*Allium cepa* (Onion)	16
2.	Garden pea (*Pisum*)	14
3.	*Brassica oleracea* (Cabbage)	18
4.	*Raphanus sativus* (Raddish)	18
5.	Tomato	24
6.	*Triticum vulgare* (bread wheat)	42
7.	*Zea mays* (Indian corn)	20
8.	*Oryza sativa* (Rice)	24
9.	Sugar cane	80
10.	*Gossipium hirsutum* (upland cotton)	52
11.	*Ophioglossum* (Adder's tongue fern)	1262
	In Fungi	
12.	*Penicillium*	4
13.	*Neurospora crassa*	7
14.	*Saccharomyces* (yeast)	17
	In Protista	
15.	Slime mold (*Dictyostelium*)	7
16.	*Amoeba proteus*	250

als of a species. Chromosome number is used in the identification of species and in tracing the relationship within the species. The chromosome number of some of the animals and plants is given in the following table :-

Animals are basically diploid. In plants - Protists and most fungi are **haploid** (i.e. they contain only one set of chromosomes). Their number of chromosomes is designated by **n.** The zygote is the only diploid phase (with **2n** number of chromosomes) in their life cycle. In bryophytes and pteridophytes the gametophyte is haploid and sporophyte diploid.

Polyploidy is very common in plants and more frequent in cultivated or domesticated plants. Common bread wheat is a **hexaploid** and seedless edible banana are usually **triploids**. Polyploids have been experimentally induced in citrus fruits, oranges, lemons, in cotton etc.

Polyploidy is rare in animals. They tend to be diploids. Organisms with very large number of chromosomes are likely to be polyploids, for example - Amoeba, geometrid moth.
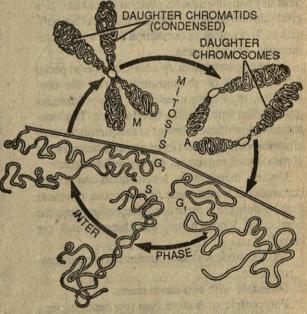
Fig. 29.2 Chromosome cycle

Chromosome Cycle

Chromosomes exhibit cyclic change in shape

and size during cell cycle. In the nondividing interphase nucleus, the chromosomes are extended, long and thin and form an interwoven network of fine twisted but uncoiled threads of **chromatin** . During S-phase of cell cycle, they replicate and the two chromatids remain attached. During cell division the long chromatin threads condense into compact structures by helical coiling. In **prophase** of cell division the chromosomes appear as distinct threads and by **metaphase** and also in **anaphase** these become short compact, bodies having definite shapes and sizes and can be counted. In anaphase these appear as rod-shaped, V-shaped, L-shaped or J-shaped. The chromosomes are studied and described at this stage or at anaphase stage. In **telophase** these again uncoil to form the chromatin net.

Morphology of Metaphase or Anaphase Chromosome

Chromosomes in metaphase and anaphase present the following distinguishing features -

1. Primary Construcution and Centromere

A part of the chromosome is marked by a constriction. It appears as a narrow clear zone in the darkly stained chromosome. This is known as **primary constriction**. Its position is constant for a given chromosome and forms a feature of identification. The primary constriction divides the chromosome into two **arms**.

In the region of primary constriction is a special differentiation of chromosome, called the **centromere**. It is associated with a proteinaceous granule-like structure, the **kinetochore**. The kinetochore provides attachment to the microtubules of chromosomal spindle fibres get and helps in the chromosomal movement during cell division.

Usually, there are two kinetochores one in each chromatid of a metaphase chromosome, but these may be more than two or none. Depending upon the number of kinetochores, the chromosomes are classified as -

1. **Monocentric** with one centromere in each chromosome.
2. **Dicentric** with two centromeres.
3. **Polycentric** with more than two centromeres.
4. **Acentric** without centromere. Such chromosomes represent freshly broken segments of chromosomes which do not survive for long and

are left in the cell cytoplasm during cell division.

5. **Diffused or non-located or Holocentric** with a large number of centromeres scattered throughout the length of chromosome. The microtu-
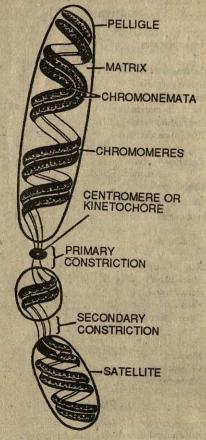
Fig. 29.3 Structure of an anaphase chromosome to show different parts of a chromosome.

bules of spindle fibres are attached at many points along the chromosome arms.

Based on the location of primary constriction and kinetochore, the chromosomes are described as -

1. **Acrocentric** are rod-shaped chromosomes with **terminal centromere** so that they possess only one arm.
2. **Telocentric** are also rod-shaped chromosomes but with a **subterminal centromere**. In telocentric chromosomes one arm is very long and the other one is very short.
3. **Submetacentric** are L-shaped chromosomes with centromere slightly away from the mid-

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point so that the two arms of the chromosome are unequal.

4. **Metacentric** are V-shaped chromosomes in which centromere lies in the middle of chromosome so that the two arms of the chromosome are almost equal.

3. Tertiary Constriction

The tertiary constrictions are present in nearly all the chromosomes. Their significance is not known. However, these help to distinguish one chromosome from others.
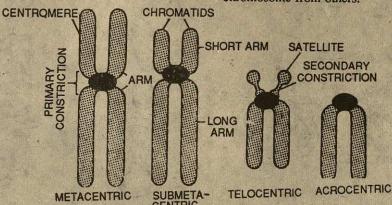
Fig. 29.4 Types of chromosomes based on the position of centromere and primary constriction.

Functions of centromere -

(*i*) It provides attachment to microtubules of chromosomal spindle fibres and helps in chromosomal movement during cell division.

(*ii*) **Nucleation centre** - The centromere serves as a nucleation centre for the polymerization of **tubulin**, the protein that forms microtubules of spindle fibres during prometaphase and metaphase.

2. Secondary Construction and Nucleolar Organizer Region (NOR)

Secondary constriction is another constant morphological feature of some chromosomes and helps in their identification. It can be distinguished from the primary constriction by the absence of marked angular deviation of chromosomal segments during anaphase movement.

In certain chromosomes, the secondary constriction is intimately associated with the nucleolus. It contains genes coding for 18S and 28S ribosomal RNA and is responsible for the formation of nucleolus. It is also known as **nucleolar organizer region (NOR)**. Its location in the chromosome is marked by a lightly stained constricted area and is constant for a given chromosome. In man, the nucelolar organizers are located in the secondary constrictions of chromosomes 13, 14, 15, 21   and 22.

4. Telomeres

The tips of the chromosomes are rounded and sealed and are called **telomeres**. These provide stability to the chromosomes and protect their individuality, because the telomeric ends do not form any permanent association with other parts of the homologous or non-homologous chromosomes, whereas the broken ends may join.

5. Satellite

The terminal part of a chromosome beyond secondary constriction is called **satellite**. It is attached to the main body of chromosome by a delicate chromalin filament. The satellite may appear as a rounded or elongated knob. It has a constant shape and size for a particular chromosome. The chromosome with satellite is known as **sat-chromosome**.

6. Chromatids

At metaphase stage a chromosome consists of two chromatids joined at the common centromere. In the beginning of anaphase, when centromere divides, the two chromatids acquire independent centromere and each one changes into a chromosome.

Molecular Organisation of Chromosome

According to DUPRAW (1965 -1979) and HANS RIS (1967), the chromatin fibres of somatic cells are about 20 nm (200 Å) in diameter. These are
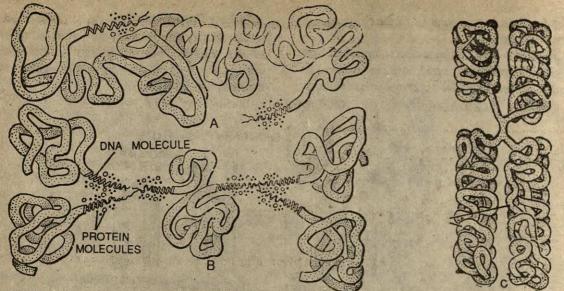
Fig. 27.5 Folded fibre model for structure of chromosome given by DUPRAW. A – At interphase ; B and C – At metaphase.

formed of **DNA** and **basic proteins** (histones). Each DNA molecule is a double helix consisting of two strands spirally intertwined. The **histone** molecules are regularly arranged in the deep grooves of DNA helix. The positive charges of the histones form electrostatic associations with negatively charged phosphate groups of DNA and provide stability and flexibility to DNA. It has been demonstrated that 20 Å DNA fibril on combination with histones forms a 100 Å thick fibril. The double helix of DNA together with the associated histones is supercoiled and is folded back and forth to form the **nucleoprotein fibre** or **chromatin fibre** which is the elementary unit of chromosome structure.

1. Histones

1. **Histones** are basic proteins because of the high percentage of basic amino acids (arginine and lysine).

2. There are five different types of histones. Four of them **H2A, H2B, H3** and **H4** are very similar in different species and are present in equimolar amounts, two of each type being present every 200 base pairs.

3. Histone H-1 is tissue-specific and is pres-

ent only once per 200 base pairs. It is loosely associated with DNA.

4. The double helix of DNA together with the associated histones is supercoiled and is folded back and forth many times to form the **nucleoprotein fibre** or **chromatin fibre**.

5. The histones associated with DNA in eukaryotic chromosomes, either serve as structural elements or cover or repress specific segments of DNA, so that they are unable to be transcribed. Such segments can be unwound and exposed for transcription by the dissolution of histones in response to certain molecular signals.

2. Nucleosome

The **nucleoprotein (chromatin) fibre** has a beaded appearance. The beads are **nucleosomes**.
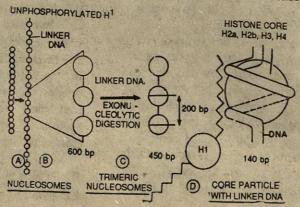
Fig 29.6 Beads on a string appearance of nucleoprotein fibre shown in model (bp-base pairs).

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These are about 10 nm in diameter and are connected together by **linker DNA** or **spacer DNA**. Each **nucleosome** is formed of a duplex DNA containing 200 base pairs, wound twice around a set of 8-histone molecules. These are differentiated into :
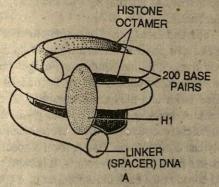
Fig. 29.7: A-A single nucleosome showing octamer histones. H-1 histone and 200 base pairs including linker DNA.

(i) **A Core particle** - The core particle consists of the **histone octamer**, formed of 8 histone molecules having two copies each of H2A, H2B, H3 and H4. It is about 11 nm in diameter and 6 nm in height. A strand of duplex DNA having 146 base pairs is tightly wrapped around this core forming two circles.

(ii) **Spacer DNA** - It is a small segment of DNA having just four base pairs. One unit of histone H-1 is associated with it. There is a considerable variation in the length of spacer region in different species varying from no base pairs to about 80 base pairs in sea urchin sperm.

3. Nucleosome Packing

The thin chromatin fibre of interphase nucleus is a linear array of nucleosomes like beads on a string. The thick chromatin fibre 20 nm to 30 nm arises by spiral coiling of thin chromatin fibre. It has a
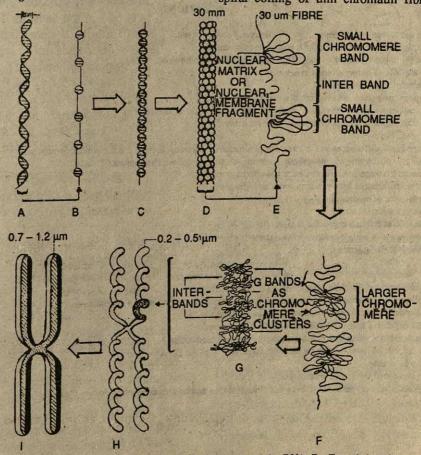
Fig. 29.8 Summary depicting the levels of organization in chromosomes. A - DNA; B - Extended nucleosomes; C - 10 nm fibre; D - 30 nm fibre with condensed nucleosomes; E - Chromomere and interband chromatin; F - clustering of chromomeres; G - chromosome bands, H and I - chromosome.

solenoid type of ultrastructure and has 6-7 nucleo-somes per turn.

In mitotic chromosome, the solenoid is packed into another helix, the supersolenoid with a diameter of 400 nm. The super-solenoid is condensed further to produce the final shape and dimensions of metaphase or anaphase chromosome.

POLYTENE CHROMOSOMES

Polytene chromosomes are giant type of inter-phase chromosomes that are very large and visible with the naked eye. These giant chromosomes are found in the cells of salivary glands of *Drosophila* and *Chironomus*, in the cells of Malphigian tu-bules, epithelial lining of gut of *Drosophila* and in the cells of fat bodies of larval stages of certain Diptera. These were first observed by BALBIANI in 1881 in the salivary glands of *Chironomous* and hence are called **salivary gland chromosomes.**

Polytene chromosomes are **multistranded** being composed of a large number of chromatin fibres or **chromonema.** Their number has been estimated to be 1024 by PAINTER and 16,000 by BEARMANN.

Bands, Interbands and Genes — A polytene chromosome presents a distinct pattern of dark coloured **bands** alternating with the light coloured **interbands.**

The **bands** are formed of **heterochromatin** and are Feulgen positive. These are darkly stained with basic dyes. The interbands are Feulgen negative and light coloured. Bands are formed of super-coiled DNA and thus are comparable to chomo-meres. A band is formed by the positioning of similar chromomeres of all the chromonemata of a polytene chromosome. Bands form a specific pat-tern in a particular chromosome. It is characteristic and constant for each chromosome of a species.

QUESTIONS

1. Describe the structure and physiology of eukaryotic chromosome.
2. Describe the molecular structure of a eukaryotic chromosome.
3. Describe the salient features of the folded fibre model of chromosome.
4. Explain the role of chromosomes in heredity.
5. Describe role of centromere.
6. How protein molecules are associated with DNA molecule ?
7. What is 'nucleolar organizer region' in the chromosome? What is its role ?
8. What is unistranded concept of chromosome structure ?
9. What is nucleoid ?
10. Enumerate basic differences in the structure of a bacterial chromosome and a eukaryotic chromosome?
11. How will you differentiate a metaphase chromosome from anaphase chromosome ?
12. Differentiate between a viral and a bacterial chromosome.
13. Summarise differences between karyotype and idiogram.
14. What is the role of centromere ?
15. What is nucleation centre ?
16. Describe role of nuclear organizer region.
17. What do you mean by telocentric and metacentric chromosome ?
18. Define the following terms :

(*i*)	Satellite	(*ii*)	Telomere	(*iii*)	Centromere
(*iv*)	Kinetochore	(*v*)	Nucleation centre	(*vi*)	Basic proteins
(*vii*)	Submetacentric chromosome	(*viii*)	Chromatin fibre	(*ix*)	Karyotype

19. How will you differentiate between primary and secondary constrictions in a chromosome ?
20. Why secondary constriction is known as nucleolar organizer ?
21. Name the organism where RNA acts as hereditary material.
22. How many DNA double helical fibres are present in a chromosome?
23. What is the role of basic proteins which are associated with the DNA molecule ?
24. Name the scientists -
    (*i*) Who coined the term chromosome ?
    (*ii*) Who described parallelism between chromosomes and transmission of hereditary factors?

Cell Division

HISTORY

NAGELI (1846), first pointed out that new cells are always formed from the pre-existing cells. RUDOLF VIRCHOW (1855) supported the view and put forward the popular generalization — *'Omnis cellulae cellula'* (the cells arise from pre-existing cells). The process of cell division in plant cells was first described by STRASBURGER (1870). FLEMMING (1882) described cell division in animal cells and coined the term **mitosis** (Gr. *mitos,* thread) with reference to thread-like appearance of chromosomes early in cell division.

When a cell divides, its nucleus does likewise. The nucleus contains chromosomes. That means cell division ensures accurate division of chromosomes so as to maintain genetic uniformity. The chromosomes are formed of DNA. Therefore, it requires replication of DNA. Thus cell division involves three major events – 1. DNA replication ; 2. Nuclear division or **karyokinesis** and 3. Division of cytoplasm or **cytokinesis**.

Based on the behaviour of chromosomes, the cell divisions are of two types —

1. **Mitotic cell division or Mitosis** - in which the daughter cells contain the same number of chromosomes as present in the parent cell.
2. **Meiotic cell division or meiosis** - in this type, the daughter cells possess half the total number of chromosomes present in the parent cell.

MITOSIS

As a result of mitosis two daughter cells are formed. Both the daughter cells contain identical nuclei with same amount of DNA, same set of chromosomes and same hereditary instructions as present in their parent cell. It occurs only in the vegetative or are present in their parent cell. It occurs only in the vegetative or somatic cells and is also described as **somatic or equatorial division.**

The Cell Cycle

The life cycle of a cell begins with the formation of daughter cells at the end of telophase. These daughter cells are smaller than the parent cells. Moreover, their DNA content is just half of the parent nucleus. These synthesize new cytoplasmic and nuclear material till the total volume of each cell becomes four times of its original volume and the DNA content gets doubled by the
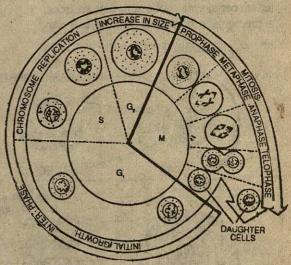
Fig.30.1   The Cell Cycle

replication of DNA. After this the cell is again ready to undergo division. it means the cycle involves two distinct phases :

1. **Interphase** (non-dividing period)
2. **Cell division or Mitosis** (period of division).

Interphase

Interphase is the interval period between two successive cell divisions, when the chromatin material remains in highly attenuated conditions. Though apparently inactive, the nucleus and cytoplasm are very active metabolically and synthetically ; synthesizing DNA and all those substances which are essential for cell division. Therefore, interphase can be described as **preparatory phase** also.

Biologists divide interphase into three distinct periods on the basis of synthetic activities.

(i) **First growth period** or **First gap period** (G₁ period) – The young daughter cell grows in size. In cells that soon enter the division phase, those substances and enzymes (RNA and proteins) which are necessary for DNA synthesis are also synthesized.

(ii) **Synthetic period** (S-period) – It is characterised by the replication of DNA. The S-period in vertebrate cells is of about 6-8 hours duration.

(iii) **Second growth period** or **Second gap period** (G₂ period) – It is characterised by increased nuclear volume. During its tenure certain metabolic activities occur as a prerequisite of cell division. Nucleolar RNA, ribosomal RNA, messenger RNA are all synthesized in G₂ substage.

Karyokinesis

The process of karyokinesis includes the division of nucleus into two daughter nuclei. It is the process which involves an unbroken series of events, but for the sake of description, it is separated into phases or stages : prophase, metaphase, anaphase, and telophase.

1. **The Prophase** –The nuclear division (mitosis) begins with **prophase**. The important events during this phase are given below —

A. Nuclear Changes

1. The chromatin material of the nucleus gradually condenses by losing water into distinct chromatin threads.

2. The chromatin threads coil like cylindrical spring and in so doing these gradually
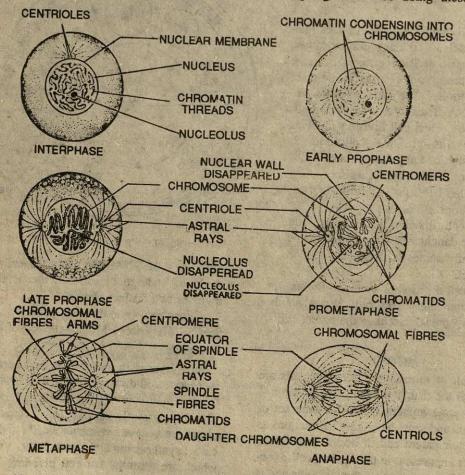
Fig. 30.2 Diagrammatic representation of different stages of mitosis in animal cell.

become shorter and thicker and form the chromosomes.

3. The proteinous matrix gets deposited around the chromosomes, so that these become more and more distinct.

4. Each chromosome is already doubled due to the doubling of DNA contents in interphase.

5. By the end of prophase (late prophase) the two chromatids of each chromosome become more distinct and each chromosome appears to be splitted up lengthwise.

6. The nucleolus and nuclear membrane disappear by the end of prophase.

B. Cytoplasmic Events

1. Each of the two centrioles divide into two and then one part of the daughter centrioles moves towards the opposite poles.

2. Astral rays radiate out from each daughter centriole.

2. Metaphase

The metaphase is marked by the appearance of spindle and arrangement of chromosomes on the equator of spindle.

1. The microtubules in the cytoplasm of the cell orient in between the centrioles of the opposite poles and form the spindle. Such a spindle is known as *amphiaster*.

2. The chromosomes from periphery of the nucleus migrate towards equator of the spindle. These orient themselves on the equator in such a fashion that their centromeres lie on the equator and are attached to the chromosomal fibres of the spindle whereas the arms are oriented towards the poles.

3. Each chromosome becomes more compact and short and its two chromatids are distinctly visible.

4. The centromere of each chromosome also divide so that the chromatids of each chromosome are ready to separate.

3. Anaphase

1. The division of centromere marks the beginning of anaphase. It initiates the separation of two sister chromatids into two daughter chromosomes.

2. The daughter chromosomes move apart and migrate towards opposite poles.

3. The movement of chromosomes is governed by the contraction of spindle fibres. The centromere is pulled first towards pole of the spindle and the arms of chromosomes are dragged behind.

4. Therefore, in anaphase, the arms of daughter chromosomes are directed towards the equator and centromeres towards the pole of the equator.

5. As the chromosomes move to their respective poles, they assume characteristic V, J, I or L-shapes.

4. Telophase

1. On reaching the poles of the spindle the chromosomes form two groups, one on either pole.

2. Chromosomes begin to uncoil and form chromatin net.

3. Astral rays and spindle disappear.

4. The nuclear envelope and nucleolus appear.
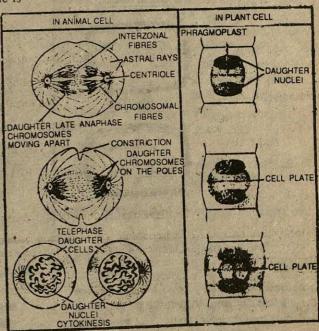
Fig. 30.3. Cytokinesis in animal and plant cells.
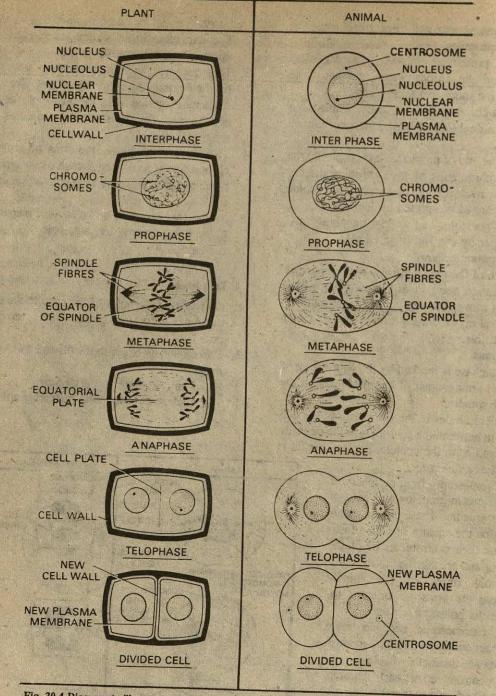
Fig. 30.4 Diagram to illustrate differences in the process of mitosis in plant and animal cells.

Cytokinesis

Cytokinesis is the division of cytoplasm following the nuclear division, so that the parent cell is divided into two daughter cells. The process of cytokinesis is different in plant and animal cells.

(A) Cytokinesis in animal cells - In case of animal cells the cell cytoplasm divides by constriction, which appears on the equator and gradually deepens and converges on all the sides and pinches off the parent cell into two daughter cells.

(B) Cytokinesis in plant cells - In plant cells, a cell plate is formed at the equator of spindle and is completed at the periphery. The primary walls are deposited on either side of the cell plate.

Significance of Mitosis

1. Mitosis ensures a continuous succession of similarly endowed cells, because from one dividing cell two daughter cells with exactly the same number and the same kinds of chromosomes are formed.

2. Mitosis is a significant aspect of the growth of living matter. It ensures that the new cytoplasm is accompanied by an appropriate amount of governing nuclear material. Individual cells cannot grow indefinitely and their size remains within economical limits with respect to the intake of foodstuffs and their transformation into energy and new cytoplasm. As a result of mitosis each new cell receives a set of chromosomes to regulate the activities of the cytoplasm.

3. Mitotic divisions help not only in the increase of size by cell accumulation but also in replacing the old and damaged tissue by the new cells.

MEIOSIS

Definition

Meiosis is a specialized and much complicated type of cell division, occurring only in the diploid reproductive cells and results in the formation of haploid **sex cells** or **gametes**. The term meiosis was coined by MOORE and FARMER (1905).

The gametes, formed as a result of meiosis, possess half the number of chromosomes as found in the parent cells and their chromosome number is represented by **n**, whereas the zygote formed by the fusion (fertilization) of male and female gametes and the cells derived from it are known as **diploid** and their chromosome number is symbolized by **2n**. The two similar chromosomes of a diploid cell are known as 'homologous chromosomes' or 'homologous pair'. The chromosomes of a homologous pair are brought together in the zygote by the union of male and female gametes from the parents.

Occurrence of Meiosis

Meiosis occurs in the life-cycle of each and every living being whether a plant or an animal. It halves the genome and ensures an alternation for haploid and diploid generations. In haploid organisms it occurs soon after the fusion of gametes. In majority of plants and animals (diploid organisms) meiosis occurs during gamete formation. The cells undergoing meiosis are known as **meiocytes**. In animals the meiocyte are the **primary spermatocytes** and **primary oocytes**, while in plants these are represented by **sporocytes**. The relative amounts of RNA and DNA are supposed to initiate meiosis in some way. If the ratio of RNA to DNA is high the cell will undergo meiosis but if reverse is the case it will lead to mitosis.

Process of Meiosis

In meiosis two complete cell divisions follow in close sequence with or without a short interphase between them. 1. The first meiotic division is known as **reduction division** or **heterotypic division.** In it the diploid parent cell divides into two daughter cells with haploid chromosome number. 2. The second division is known as **homeotypic division** and is a simple mitotic division in which the two haploid cells formed as a result of heterotypic division divide again forming four daughter cells, each with haploid number of chromosomes. Each of the two meiotic cell divisions is further distinguished into phases : prophase, metaphase, anaphase and telophase.

A. Heterotypic Division or First Nuclear Division

1. Prophase I

The prophase of first meiotic division is of longer duration and is profoundly modified. It is distinguished into following five substages : Leptonema, Zygonema, Pachynema, Diplonema and Diakinesis.

The meiocyte is comparatively large and possesses a large nucleus. It contains diploid number of chromosomes which form a network.

1. **Leptonema** (= Leptotene) — 1. The nucleus in leptonema stage is large. It further increases in size.

2. The chromosomes appear as long fine threads
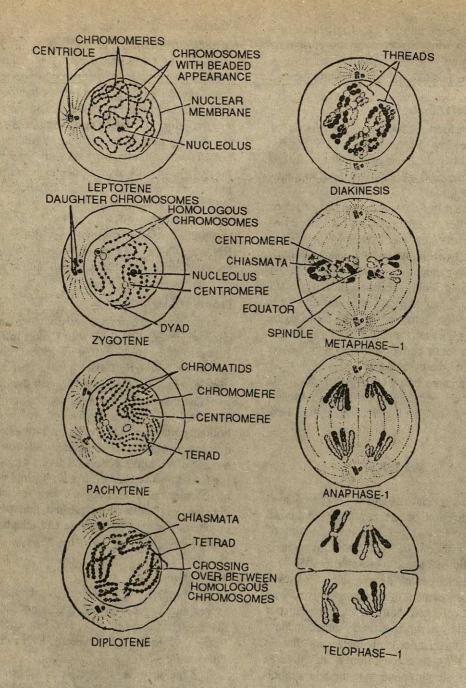
Fig. 30.5 Diagrammatic representation of different stages in the heterotypic division or first meiotic division.

by the condensation of chromatin material.

3. Each chromosome appears to be longitudinally single but its DNA is already duplicated so that it is formed of two chromatids. However, the chromatids are tightly wound together.

4. Chromosomes have beaded appearance due to the presence of **chomomeres**. These are darkly stained regions alternating with light coloured regions. Their number, size and position are constant and identical in homologous chromo-

somes. They represent highly coiled regions of DNA alternating with light coloured uncoiled segments.

2. **Zygonema** (= Zygotene) — (i) Shortening of chromosomes by further coiling makes them distinctly visible.

   (ii) The homologous chromosomes of each pair are attracted towards each other. They come close together and pair. The pairing of homologous chromosomes is known as **synapsis**.

   (iii) The pairing may start at one or more points along the length of homologues. It then proceeds in a zipper-like fashion.

   (iv) The pairing is a very accurate process and involves point to point or gene to gene pairing over the entire length of homologues.

   (v) Each pair of synapsed homologues is known as **bivalent**.

   (vi) The nucleolus increases in size and centrioles move apart.

3. **Pachynema** (= Pachytene) — During pachytene stage the paired chromosomes of each bivalent get shortened and thickened and are more distinct. They twine around each other. Further, sister chromatids in each chromosome become distinct by the appearance of longitudinal furrow. Therefore, each bivalent now consists of four chromatids and is known as **tetrad**.

During pachynema stage, an exchange of chromatid segments between nonsister chromatids of each tetrad also takes places. This is known as **crossing over**. During crossing over the nonsister chromatids of a tetrad break at identical points. The breaks are caused by the enzyme **endonuclease**. The broken segment of nonsister chromatids interchange i.e. the broken segment of one chromatid joins with the nonsister chromatid of its tetrad by an enzyme **ligase**. The point of interchange and rejoining appears X-shaped and is known as **chiasma**. There may be one, two or more chiasmata in a tetrad. As a result of crossing over new combinations of hereditary material are formed.

4. **Diplonema** (= Diplotene) - In diplotene the synaptic forces of attraction between homologous chromosomes lapse and the homologous chromosomes uncoil and separate. But these remain in contact on **chiasmata**. Simultaneously, the chromosomes become increasingly shorter and thicker by coiling. As each bivalent becomes increasingly shorter, the chiasmata move away from the centromere and approach the ends. This phenomenon is known as **terminalization**.

5. **Diakinesis** - During diakinesis the chromosomes continue to contract so that the bivalents are thickest in this stage. Due to further terminalization the bivalents appear as rounded darkly stained bodies. During latter part of this phase the centriole and centrosphere divide and move towards the opposite poles and the nuclear membrane disappears.

2. Metaphase - I

During metaphase-I spindle is formed between the two centrioles and the chromosomes are arranged on the equator of the spindle. Their centromeres are attached to the chromosomal fibres of the spindle but unlike metaphase of mitosis the arms of the chromosomes are tested on the equator and centrioles are directed towards the poles.

3. Anaphase - I

The centromeres of homologous chromosomes move towards opposite poles. As a result the two homologous chromosomes which had come close together during zygotene of prophase, now separate and reach the opposite poles (**disjunction**). By the end of anaphase two groups of haploid chromosomes are formed one on each pole of the spindle.

Unlike anaphase chromosomes of mitosis, these chromosomes still consist of two chromatids attached to the single centromere.

4. Telophase - I

The chromosomes which have reached the poles uncoil and form chromatin net. The nuclear membrane is formed around each group. Thus two haploid daughter nuclei are formed. This is followed by cytokinesis resulting in the formation of two haploid daughter cells. However, the cytokinesis may be postponed till the end of the second division and the daughter nuclei may immediately enter second meiotic division.

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PROPHASE-II

PROPHASE-II

METAPHASE-II

METAPHASE-3

ANAPHASE-II

ANAPHASE-II

TELOPHASE-II

TELOPHASE-II
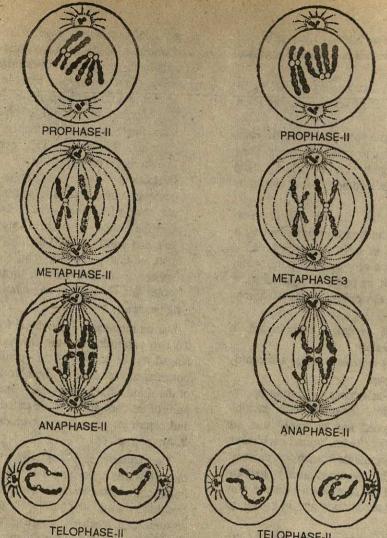
Fig. 30.6 Different stages in the second meiotic cell division in an animal cell

Interkinesis

This is the interval between the first and second meiotic division and its duration varies in different species. In this period well organised daughter cells are formed.

B.Meiotic Division-II or Homeotypic Division

The second meiotic division is essentially a mitotic division and is separated into the same four phases or stages. These changes occur simultaneously in both the haploid cells.

1. Prophase - II

The chromosomes reappear. The nuclear membrane disappears and the formation of spindle starts. Each prophase consists of two distinct chromatids attached to the single centromere.

2. Metaphase - II

The formation of spindle is completed and the chromosomes get oriented on the equator of the spindle. Now their centromeres are aligned on the equator and the arms of their chromatids are directed towards the poles of the spindle. The centromere of each chromosome is attached with the fibres from both the poles.

3. Anaphase - II

The centromere in each chromosome divides and the chromatids separate as daughter chromosomes. These are dragged towards the opposite poles. In the late anaphase the daughter chromosomes form two identical groups of haploid chromosomes one on each pole of the spindle.

4. Telophase - II

In telophase the chromosomes of each group uncoil and develop a nuclear membrane and is organised into a nucleus. The nuclear division is followed by the division of cytoplasm (cytokinesis).

Therefore, as a result of meiosis four cells are formed and each cell has haploid number of chromosomes.

Significance of Meiosis

(i) The meiosis is a logical and necessary part in the life-cycle of sexually reproducing animals as it helps in restoring the definite number of chromosomes characteristic of that species.

(ii) As a result of meiosis, the gametes are formed from the reproductive bodies. Each gamete possesses chromosomes just half in number of the somatic cells. The fusion of gametes at the time of fertilization results in their duplica-

Table 30.1: Comparison between Mitosis and Meiosis

Meiosis	Mitosis
1. Meiosis occurs at the time of gamete formation in the reproductive cells.	1. Mitosis occurs in the somatic cells and all the body cells multiply in number by this type of division.
2. The Meiosis includes two successive divisions taking place one after the other. Thus the phases as found in mitosis are repeated twice in meiosis.	2. The whole process of division is completed in one sequence.
First Prophase	
3. The first prophase is of a very long duration and is completed in several steps. It is differentiated into following substages or phases ; leptotene, zygotene, pachytene, diplotene and diakiness.	3. The prophase is comparatively of shorter duration and is not differentiated into substages or phases.
4. In the beginning of prophase the chromosomes are effectively single.	4. The chromosomes are splitted longitudinally into two sister chromatids and hence are double structures.
5. The homologous chromosomes pair and form dyads.	5. No pairing occurs in the chromosomes.
6. The chromosomes of a pair twine round each other in *paranemic manner*.	6. The chromatids are coiled in *plectanemic manner*.
7. Doubling of chromosomes occurs in pachytene stage of prophase.	7. Doubling of chromosomes occurs in interphase.
8. Crossing over and chiasmata formation occur during pachytene stage, as a result of which exchange of genetic material takes place in the chromatids of homologous chromosomes.	8. No crossing over and chiasmata formation occurs.
9. Nucleolus and nuclear membrane disappear late in prophase and the formation of achromatic figure is completed with diakinesis.	9. The nucleolus and nuclear membrane disappear late in prophase and the formation of nuclear spindle is completed with the commencement of metaphase.
Metaphase	
10. In metaphase the chromosomes are in the form of tetrads consisting of four chromatids.	10. In metaphase each chromosome is a dyad consisting of two chromatids only.
11. The tetrads orient on the equator in such a way that their two centromeres are placed equidistant from the equator and face the poles while their arms are directed tosards the equator.	11. The orientation of dyads is just the opposite, the centromeres lie on the equator and arms are directed towards the poles.
12. The centromeres do not divide but the homologous chromosomes simply separate out into dyads.	12. The centromere of each bivalent divides in metaphase into two and the members of a dyad separate.
Anaphase	
13. The anaphase chromosomes are bivalent, each consisting of two chromatids.	13. The anaphase chromosomes which separate out are single.
14. The chromosomes are very short and much thickened.	14. The chromosomes are comparatively longer and less thickened.
Telophase	
15. The first telophase is not of universal occurrence in meiosis, since the dividing nucleus may directly pass from anaphase to 2nd prophase.	15. The telophase is of universal occurrence and is followed by cytoplasmic division.
Significance	
16. As a result of meiosis four cells are formed.	16. As a result of mitosis only two cells are formed.
17. The daughter cells are haploid and contain just half the	17. The daughter cells are diploid, consisting of the same

(contd.)

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Meiosis	Mitosis
number of chromosomes as found in the parent cell.	cromosomal configuration as found in parent cell.
18. The daughter cells are not all alike and they do not resemble the parent cell because of crossing over and halving of chromosomes.	18. The daughter cells produced as a result of mitosis are all alike and similar to the parent cell.
19. Time taken for meiotic division is much larger as compared to mitotic division.	19. Time taken for mitotic division is much shorter.

tion. Thus meiosis is the step that avoids the multiplication of chromosome number in the somatic cells and helps in stability of a species.

(iii) During the process of meiosis, **crossing over** takes place between the chromosomes of a homologous pair which are received one from each parent. The crossing over and chiasmata formation result in the exchange of chromosome pieces between the two homologues. Thus new combinations of genetic or hereditary materials are facilitated. Thus the gametes are not all alike and have a variable combination of genes. The random segregation of chromosomes and the new alignments of genes in them resulting from crossing over ensure genetic variations in the population. This inherited variability leads to the evolution of organisms.

UNUSUAL CELL DIVISIONS

1. Amitosis

Amitosis includes splitting of the nucleus followed by that of cytoplasm. During this cell division neither the chromosomes appear as distinct bodies nor the spindle is formed. The beginning of division is marked by the elongation of the nucleus, followed by a depression which deepens and constricts the nucleus into two. Simultaneously, the cytoplasm also divides into two. This type of cell division is seen in certain proto-zoans and yeast etc. It is a means of asexual reproduction (Fission).
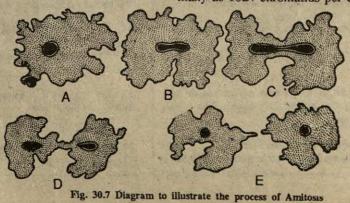
In **bacteria** the cell division results in binary fission or budding. Their single chromosome replicates by the replication of its DNA. The two daughter chromosomes formed this way may initiate division of bacterial cell either by fission or by evagination into buds.

2. Endoploidy or Endoduplication

In certain abnormal conditions, the nuclear division may stop in between after the replication of chromosomes. This leads to doubling of chromosomes in the cell producing tetraploid cells. This process is known as **endoploidy** or **endoduplication** (duplication of chromosomes without nuclear and cytoplasmic division or retardation of cell division at anaphase).

In certain tissues of some animals like Malphigian tubules, gut epithelium and salivary glands of dipteran insects, the division of chromosomes into two chromatids is not followed by the division of their centromere. Therefore, the chromatids never separate to form daughter chromosomes. resulting in the formation of chromosomes with more than two chromatids. This phenomenon is known as **polyteny** and these multistranded chromosomes are called **polytene chromosomes** (*poly* – many + *tene* – threads). The salivary gland chromosomes of *Drossophila* may have as many as 1024 chromatids per chromosome.

Fig. 30.7 Diagram to illustrate the process of Amitosis

1. Give a brief account of somatic cell division with the help of fully labelled sketches.
2. Describe the process of meiosis. What is its significance in sexually reproducing organisms ?
3. Enumerate various events that occur during prophase I of meiotic division.
4. Differentiate between mitosis and meiosis.
5. Compare and contrast the prophase stage of mitosis and meiosis.
6. What do you understand by cell cycle? Describe all those events that occur during interphase of cell cycle that prepare the cell for nuclear division.
7. Discuss the role of meiosis and the end products in spermatogenesis, oogenesis, microsporogenesis and megasporogenesis.
8. In sexually reproducing organisms the species-specific chromosome number is maintained constant irrespective of the fusion of gametes from two different sources. Explain.
9. What is a genome? How many genomes are there in a haploid and a diploid organism?
10. What is the difference between karyokinesis and cytokinesis?
11. Mention three basic differences between mitosis and meiosis.
12. Describe significance of prophase-I of meiosis.
13. Distinguish between cytokinesis in a plant and an animal cell.
14. Why the term resting stage used earlier for interphase is not appropriate?
15. Describe the chemical nature and function of spindle fibres during cell division.
16. What do you mean by the terms:
    (i) Equatorial division   (ii) Disjunction   (iii) Cell cycle   (iv) Growth phase
    (v) Terminalization   (vi) Oogenesis
17. Define the following-
    (i) Synapsis   (ii) Crossing over   (iii) Diplotene   (iv) Chiasmata
18. How the process of mitosis and meiosis provide physical basis for the law of segregation and independent assortment?
19. What is the significance of prophase-I of meiosis?
20. What are basic differences in all diplotene and pachytene stages?
21. Mention three basic differences between mitosis and meiosis.
22. What are the sites of meiosis in plants and animals?
23. What is the name of the process by which sperm are produced in male individuals?
24. How many sperms will be produced from 100 primary spermatocytes and how many eggs will be produced from 100 primary oocytes?
25. In how many divisions 64 diploid cells will be produced from a single diploid cell?
26. What are the characteristic activities during G_2 period of interphase?
27. The number of chromosome in onion cells is 16 (8 pairs). What will be the number of chromosomes after three generations. if there is no meiosis at the time of gamete formation?
28. What will be the number of chromosomes in a cell in which karyokinesis is completed but cytokinesis has not taken place. (Presume the number of chromosome in the parent cell is 2n).
29. Give proper term for each of the following:
    (i) The pairing of paternal and maternal chromosomes during prophase I of meiosis .... (Synapsis)
    (ii) The exchange of parts in homologous (maternal and paternal) chromosomes during prophase I of meiosis ....
                    (Crossing over)
    (iii) Cytological manifestations of crossing over in the form of points of contact between chromatids of maternal and paternal chromosomes...................................... (Chiasmata)
    (iv) Displacement of chiasmata along the length of paired chromosomes towards the ends .... (Terminalization)
    (v) The point by which a chromosome is attached to the spindle fibre .... (Centromere)
    (vi) The process of separation of homologous chromosomes during anaphase I of meiosis .... (Disjunction)
    (vii) The failure in separation of homologous chromosomes that had paired during synapsis ....
                    (Nondisjunction)
    (viii) The structure that initiates spindle formation in animal cells but is absent in plant cells .... (Centriole)
30. Fill in the blanks:
    (i) The type of nuclear division that does not involve formation of distinct chromosomes and the formation of spindle is ....
                    (Amitosis)
    (ii) The process of DNA replication without the division of nucleus resulting in the formation of polyploid cells is known as .... (Endoploidy/endoduplication)
    (iii) The .... is morphological equivalent of genetic crossing over.
                    (Chiasma)
    (iv) Sister chromatids that form daughter chromosomes in anaphase of mitosis are, joined together at the ....
    (v) Crossing over is a unique feature of .... It helps in maintaining chromosome number constant in the daughter cells.
    (vi) A cell ready to undergo meiosis is called ....
    (vii) Crossing over occurs in.........stage of prophase I of ....
    (viii) .... occurs during the formation of gametes and .... in plants.
31. Draw a labelled diagrams to show the various stages of mitosis.

Extranuclear Genes and Cytoplasmic Inheritance

Basically genes are located in the chromosomes and they are responsible for nuclear inheritance. But not all genes in eukaryotic cells are located on the chromosomes.

In 1950's Dr. RUTH SANGER and his colleagues suggested the possible role of cytoplasm in certain cases of inheritance. Cytoplasm in such cases contains self perpetuating hereditary particles formed of DNA. This DNA may be present in mitochondria, plastids or some foreign organisms etc. The self duplicating hereditary material of cytoplasm is called **plasmon** and the cytoplasmic units of inheritance are called **plasmagenes**.

The crosses exhibiting following types of results suggest extrachromosomal inheritance:

1. **Difference in reciprocal cross results:** In cases of chromosomal heredity, the results of reciprocal crosses are ordinarily identical but in the cases of cytoplasmic inheritance the results of reciprocal crosses are different.
2. **Maternal influence:** The progeny of reciprocal crosses for a certain character are found to exhibit characteristics of female parent. Maternal influence usually implies transmission through cytoplasm.
3. **Infection-like transmission:** When a heritable phenotype is transmitted without nuclear trans-

mission, it suggests that some particles from the cytoplasm of the parent/parents have been transmitted to the offsprings.

4. **Indifference to nuclear substitution:** When a particular genotype exhibiting a specific character is replaced by a nucleus having alternative genotype, it does not change the phenotype and suggests the possibility of cytoplasmic inheritance.
5. **Nonsegregation and non-Mendelian segregation:** Segregation is characteristic of Mendelian and chromosomal inheritance. Failure to show segregation may indicate extrachromosomal heredity. Even if segregation occurs but in a fashion inconsistent with the segregation of chromosomes, the results may suggest the possibility of nonchromosomal inheritance.

Examples of Cytoplasmic Inheritance in Animals

A. Cases showing Maternal Effects

1. **Maternal influence on shell coiling in snail Limneae**– The direction of coiling of the shell in water snail *Limnaea* illustrates the influence of maternal genes acting through effects produced in the cytoplasm. Snails exhibit two types of coiling of their shell – (i) the shells coiled towards right are known as **dextral**, and
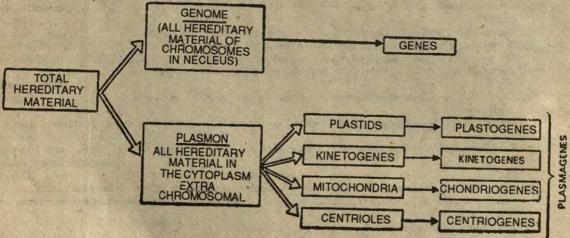
Fig. 31.1 Possible types of hereditary materials in living organisms

(ii) those coiled towards left are **sinistral**. The dextral coiling is dominant and governed by the gene **D**. The sinistral coiling is recessive and is determined by the gene **d**.

The experiments of BOYCOTT, DIVER and GASTRIC and explanation given by STURTEVANT indicate that the character of coiling is determined by the gene of the mother and not by the individual's own gene.

(i) If a **dextral female** is crossed with **sinistral male**, all the F_1 snails possess dextral shell. Surprisingly even in F_2 also all the offsprings possess dextral shell irrespective of

the fact that a few of them possessed recessive genes and were supposed to develop sinistral coiling.

(ii) In a reciprocal cross between **sinistral female** and **dextral male**, all the F_1 offsprings which according to their genotype were supposed to be dextral, were found to develop sinistral shell coiling and in F_2 generation all the offsprings developed dextral coiling.

From these reciprocal crosses following abnormal observations have been collected:

(i) Some of the snails which are homozygous
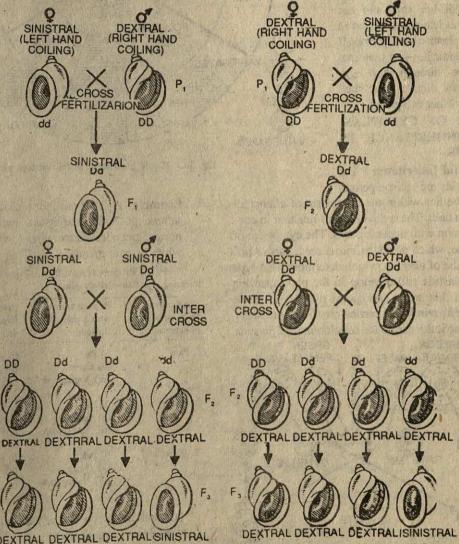
Fig. 31.2 The normal inheritance of dextral and sinistral coiling in *Limnaea peregra* showing maternal influence on its shell coiling.

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for sinistral coiling have dextral coiling similar to the mother.

(ii) Some of the snails which have gene for dextral character display sinistral coiling like the mother.

It means the offsprings irrespective of their own genotype exhibit the effect of their mother's genotype *i.e.* they resemble the mother not in the pattern of her shell but her genes that leave impression in the cytoplasm of all her eggs. It clearly indicates that maternal genotype through her egg-cytoplasm dictates the shell coiling of her offsprings.

CASES OF CYTOPLAS-MIC INHERITANCE IN PLANTS

1. Plastid Inheritance - The plastids are self-perpetuating bodies within the cytoplasm of almost all plant cells. These develop and function in conjunction with nuclear genes. The cytoplasm of ovule, which develops into a seed, carries primordia of plastids, which determine what type of plastids will develop in the plant growing from this seed. The sperm nucleus from the pollen grain which carries very little cytoplasm, has no influence on the development of plastids.
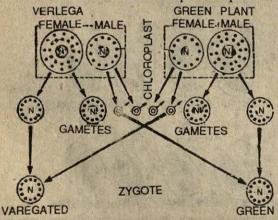
Fig 31.4 Cytoplasmic inheritance of leaf variegation in plants
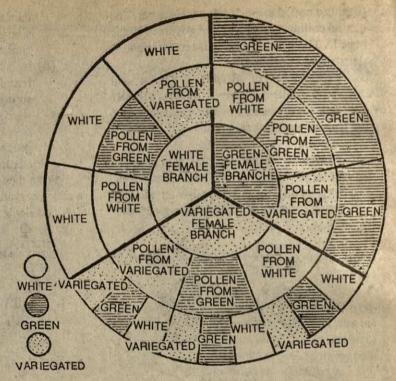
Fig. 31.3 Plastid inheritence in four-o'clock plant.

Example - A variety of four o'clock, *Mirabilis jalapa,* possesses variegated leaves, i.e. the normal green leaves are spotted with patches of white or pale green colour. This is known as

Table 31.1 Progeny from different types of branches of a variegated four-o'clock plant

Branch type from which pollens taken	Branch type on which pollinated flowers	Progeny grown from hybrid seeds
1. Pale	(i) Pale	(i) Pale
	(ii) Green	(ii) Green
	(iii) Variegated	(iii) Pale, green, and variegated
2. Green	(i) Pale	(i) Pale
	(ii) Green	(ii) Green
	(iii) Variegated	(iii) Pale, green, and variegated
3. Variegated	(i) Pale	(i) Pale
	(ii) Green	(ii) Green
	(iii) Variegated	(iii) Pale, green, and variegated

albomaculatus type of leaf variegation. CORREN found that (i) seeds taken from branch which is entirely green produce plants which are entirely green and seeds taken from a branch which is wholly pale produce plants without chlorophyll

and naturally are unable to survive. Moreover, seeds taken from variegated branches produce green, yellow and variegated plants. The pollen used to fertilize flowers in the above cases produced no difference upon the characteristic in question.

Conclusion – Variegation is maternal and is determined by self-perpetuating bodies localized in the cytoplasm. These are known as plastome. These are transmitted generation after generation through the cytoplasm carried on by the ovule.

VIRAL CHROMOSOMES

In viruses and bacteriophages a single molecule of DNA or RNA represents the viral chromosome. It may be single-stranded or double-stranded.

Table 31.2: The size and structure of the genomes of some viruses

	Organism	Type of Genome	Molecular Weight ($\times 10^{-6}$ daltons)	Approximate no. of genes
	RNA Viruses			
1.	Potato spindle tuber Virus.	Linear single-stranded RNA	0.025 – 0.11	< 1
2.	Polio Virus	Linear single-stranded RNA	2.6	4 (3)
	DNA Viruses			
3.	φ ×174 coliphage	Circular single-stranded DNA	1.7	6(8)
4.	Polyoma Virus	Circular double-stranded DNA	3.0	5
5.	SV 40 Virus	Circular double-stranded DNA	3.2	6
6.	Influenza Virus	Linear single-stranded DNA	3.6	12
7.	Mouse leukemia Virus	Linear single-stranded RNA (can be dissociated into fragments)	11.2	37
8.	Reovirus	Linear double-stranded RNA	15	25
9.	Adenovirus type 12	Linear double-stranded DNA	21-22	38
10.	Herpes simplex	Linear double-stranded DNA	96	160

QUESTIONS

1. Write an essay on cytoplasmic inheritance. Explain it with one suitable example from plants.
2. How the crosses exhibiting inheritance can be differentiated from the crosses exhibiting the results of chromosomal inheritance or nuclear inheritance?
3. Write short notes on :
   (1) Plasmagenes
   (2) Plasmon
   (3) Inheritance of leaf variegation in four o'clock plant
   (4) Chromogen
4. A pure sinistral female snail is crossed with a pure dextural male. Give the appearance of the F₁ with reasons of each isntance. Give the phenotype of F₂ and phenotypes of the F₁ if F₂ snails are self fertilized.
5. If the cytoplasm contained hereditary units or determiners and if the eggs were hybird for two different kinds of cytoplasmic determiners, would such determiners segregate from each other at the reduction division in the way the alleles do? Tell why or why not?
6. In four o'clock the foliage is variegated. Some branches have all green leaves, some are pale and some are variegated with patches of green, pale and a mixture of green and pale. Fill in the space in the last column below, showing what type of plant would be grown from seeds produced by different pollinations. The green colour is in the plastids in the leaves' part of the cytoplasma.

Branch supplying pollen seeds	Branch with pollinated flowers	Colour of plant grown from these seeds
Green	Pale	1
	Green	2
	Variegated	3
Pale	Pale	4
	Green	5
	Variegated	6
Variegated	Pale	7
	Green	8
	Variegated	9

1. Pale, 2. Green, 3. Pale, variegated and green 1 : 2 : 1; 4. Pale, 5. Green, 6. Pale, variegated and green 1 : 2 : 1; 7. Pale, 8. Green, 9. Pale, variegated and green 1 : 2 : 1 ratio.

□ □

Linkage Recombination and Linkage Maps

LINKAGE AND LINKAGE GROUPS

According to 'Chromosome Theory of Inheritance', the genes are carried in the chromosomes. The number of genes per individual far exceeds the number of chromosome pairs. Hence, it is obvious that each chromosome bears many genes.

The independent assortment of characters is based on the independent assortment of non-homologous chromosomes. The genes located on the same chromosomes tend to be inherited together. *This phenomenon of inheritance of genes together and to retain their parental combination even in the offsprings is known as* linkage. The genes located in the same chromosome and being inherited together are known as linked genes, and the characters controlled by these as linked characters.

All those genes which are located in the single chromosome form one linkage group. The total number of linkage groups in an organism corresponds to the number of chromosome pairs. For example, there are 4 linkage groups in *Drosophila melanogaster*, 23 in man and 7 in sweet pea.

HISTORY

1. Coupling and Repulsion Hypothesis

Though, the concept of linkage was predicted as early as 1903 by SUTTON in his chromosome theory, the event of linkage was first observed by BATESON and PUNNET in 1906 in pea plant but it

Table 32.1 Results of Backcross of dihybrid cross

F_2 Phenotype	Number	Ratio
Purple long	296	11
Purple round	29	1
Red long	27	1
Red round	85	3

was described as coupling. They found that in sweet pea, the results of dihybrid cross involving flower colour and shape of pollen grains do not agree with the law of independent assortment. The results obtained are shown in the table 32.1 :-

P_1......Purple flower, long pollen × Red flower, round pollen
↓
F_1.....Purple flower, long pollen (Self pollinated)

When these F_1 purple, long (heterozygous) hybrids were crossed with double recessive red and round (homozygous) individuals (test cross), they failed to produce expected 1 : 1 : 1 : 1 ratio *i.e.* 25% each type in F_2 generation. These actually produced following four combinations in the ratio of 7 : 1 : 1 : 7.

P...Purple long × Red Round

P_1..Purple long × Red round (double recessive)
(back crossed)
↓

Test Cross
Progeny

Purple long	Purple round	Red long	Red round
7	1	1	7

7 Purple long : 1 purple round : 1 red long : 7 red round
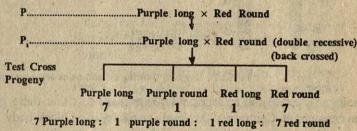
Fig. 32.1 Test cross in purple long and red round flowers

The above results of the test cross indicate that the parental combinations are seven times more numerous than the non-parental combinations. BATESON and PUNNET suggested that '*the alleles coming from the same parent tend to enter the same gamete and to be inherited together* (genetic coupling). *Similarly, the genes coming from two different parents, tend to enter different gametes and to be inherited separately and independently* (repulsion).

2. Morgan's Concept of linkage
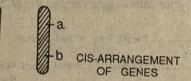
MORGAN (1910) while working on *Drosophilia melanogaster** concluded that coupling and repul-

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* Drosophilia melanogoster (fruit fly) is a very suitable organism for genetic experiments because –
(i) It can be grown in large numbers in the laboratory.
(ii) Its life cycle is completed in only 10-12 days.
(iii) A large number of progency is produced from each mating.

sion are two aspects of the same phenomenon, which he described as 'linkage'. He defined linkage as 'the tendency of genes, present in the same chromosome, to remain in their original combination and to enter together in the same gamete.

Salient Features of Theory of Linkage

1. Genes are arranged in a linear fashion in the chromosomes.

2. Genes that show linkage are situated in the chromosome.

3. Linked genes remain in their original combination during course of inheritance.

4. The genes which are closely located show strong linkage, while those, widely separated, have more chances to get separated by crossing over.

5. If the dominant alleles of the two or more pairs of linked genes are present on one chromosome and their recessive alleles of all of them on the other

In the above example, the parental combinations are several times more numerous than the new combinations. This clearly indicates that these characters are linked together. Their genes are located in the same chromosome and only in 3.6% individuals these have become separated by crossing over. This is an example of incomplete linkage.

Example 2. A cross between wild type *Drosophila* with grey body vestigial wings (BBvv) and *Drosophila* with black body and long wings (bbVV) produces F_1 offsprings, all of which have grey body and long wings (BbVv). These F_1 male hybrids when back crossed with a double recessive female (test cross) having black body and vestigial wings (bbvv) produce offsprings of two types in equal proportions. These offsprings resemble the two grand-parents.

The results indicate that grey body character is inherited together with vestigial wings. It means

CIS-ARRANGEMENT OF GENES

TRANS-ARRANGEMENT OF GENES
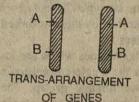
Fig 32.2   Diagram showing cis and trans arrangement of linked genes

homologue (AB/ab), this arrangement is known as **cis-arrangement**. Contrary, if the dominant allele of one pair and recessive allele of second pair are present on one chromosome and recessive and dominant alleles on the other chromosome, a homologous chromosome (Ab/aB), this arrangement is called **trans arrangement**.

Examples of Linkage

Example 1. - HUTCHINSON crossed one variety of maize having coloured and filled seeds, with another variety having colourless and shrunken seeds, all the F_1 plants produce coloured and full seeds. But in a test cross, when these F_1 female hybrids are cross pollinated with the pollens from a plant having colourless and shrunken seeds (double recessive), four types of seeds are produced. These are :

(i) Coloured full (CS)   - 4,032/8368 } = 96.4 %
(ii) Colourless shrunken (cs) - 4035/8368
(iii) Coloured shrunken (Cs) - 149/8368 } = 3.6 %
(iv) Colourless full (cS) - 152/8368

that these genes are linked together. Similarly, black body character is associated with the long wings.

In the above example, the offsprings exhibit only the parental combination of characters. Since new or non-parental combinations are not formed, this shows complete linkage. Complete linkage is seen in Drosophila males.

RECOMBINATION AND CROSSING OVER

Breeding experiments carried out on *Pisum sativum* and *Drosophila* showed that even the linked genes do not always remain together during inheritance. Sometimes these separate with an interchange of alleles due to exchange of parts between chromatids of homologous chromosomes at the time of meiosis. This results in the formation of new or non-parental combination of the old genes. This phenomenon of new combination of old genes is known as **recombination of genes** and the offsprings with new combination of characters are

GREY VESTIGIAL   BLACK LONG

GREY LONG   BLACK VESTIGIAL

CROSSING OVER

GREY VESTIGIAL   BLACK LONG   BLACK VESTIGIAL   GREY LONG
41.5%   41.5%   8.5%   8.5%
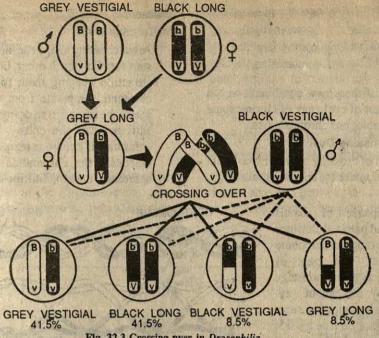
Fig. 32.3 Crossing over in *Drosophilia*
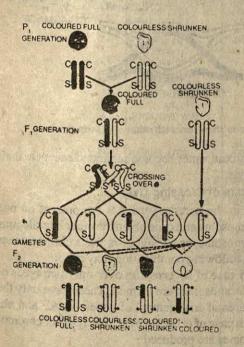
Fig. 32.4   Linkage in maize

known as **recombinant types**. The process which the genes on one chromosome are exchanged for corresponding genes of the homologous chromosome, is referred as **crossing over**.

Therefore, **crossing over** *is a physical process of interchange of corresponding parts between the*

chromatids of a homologous pair of chromosomes that results in the recombination of linked genes.
Examples

1. **Recombination in Drosophila** - A cross between a grey bodied, vestigial - winged (BBvv) and black bodied, long-winged (bbVV) Drosophila produces F_1 hybrids, all of them having grey body and long wings (BbVv). When female flies of F_1 generation (BbVv) were crossed with double recessive males having black body and vestigial wings (bbvv) - a test cross, four types of offsprings were produced as follows :

1. Grey vestigial 41.5% } **Noncross overs**
2. Black long   41.5% }   83%
3. Grey long   8.5% } **Cross overs**
4. Black vestigial 8.5% }   13%

The recombination of genes or the appearance of nonparental combinations is found in 17% of the offsprings.

2. **Recombination in Maize** - As described earlier in **linkage** a heterozygous **coloured** and **normally filled** seed plant of maize produced as a result of cross between coloured and normally filled seeds and the colourless, shrunken seeds was pollinated with pollens from colourless, shrunken seed plant (test cross), the F_2 plants had four varieties as follows :

375

(i) Coloured full

(ii) Colourless shrunken } 96.4 % - Parental combination

(iii) Coloured shrunken

(iv) Colourless full } 0.4 % - New combination

(See Fig. 32.3.)

The formation of these new combinations has occurred on account of exchange of chromosome parts between homologous chromosomes :

Mechanism of Crossing Over

The mechanism of crossing over or recombination can be studied under the following headings:

1. Synapsis

During the prophase-I of meiosis the maternal and paternal chromosomes of a homologous pair come close together and pair at **synaptotene** or zygotene substage **(synapsis)**. By the end of zygotene, the two homologous chromosomes of a pair lie side by side close together and these coil around each other forming **bivalent.**

2. Duplication of Chromosomes

During **pachytene stage** each of the homologous chromosomes in a bivalent splits longitudinally into two sister chromatids. Thus the bivalent now consists of four chromosomes known as **tetrad**. The longitudinal splitting of chromosomes is caused by the separation of already duplicated DNA molecules.

3. Crossing Over

During **diplotene stage**, when the paired chromosomes start separating, the chromatids remain in contact at one or more points and thus establish one or more exchange per bivalent. These points of contact are known as **chiasmata**. At each chiasma, two non-sister chromatids of the bivalent break at the corresponding points and then rejoin with the exchange of segments. The new chromatids formed as a result of exchange of segments are formed of segments derived from two nonsister chromatids of the bivalent.

This breakage of chromatids is brought about by enzyme, **endonuclease**. The fusion of broken segments takes place due to the action of enzyme

ligase.

4. Terminalization

After crossing over, the nonsister chromatids start repelling each other, because the forces of attraction keeping them together lapse. The chromatids separate from the centromere towards the tip and in so doing, the chiasmata also shift towards the ends. The movement of chiasmata is known as **terminalization**. Simultaneously the chromatids condense and get shortened and in diakinesis the homologous.
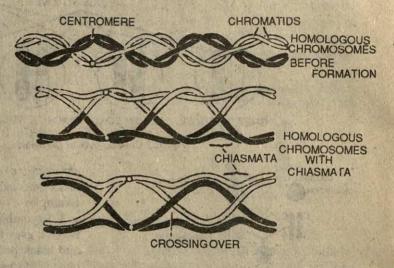
Fig. 32.5. Diagram to show the mechanism of crossing over.

chromosomes become separated except at their ends.

Results of Crossing Over

If in the parents gene AB are present on one chromosome and gene ab on the other homologous chromosome, as a result of meiosis chromosomes with following combination may arise:

(i) **In case of no crossing** over only two types of chromosomes are formed. These have only the parental arrangement of genes *i.e.* AB and ab.

(ii) **In case of crossing over** four types of chromosomes are produced :

(a) Chromosomes with parental combinations AB/ab.

(b) Chromosomes with **new combinations** of the gene, i.e. Ab and aB. This is produced due to exchange of parts between the chromatids of parental chromosomes.

From the above results, it becomes evident that during meiosis as a result of crossing over four types of cells are formed in the following proportions :

(a) Cross over   50%   (i) Ab   25%
    (Nonparental   (ii) aB   25%
    combinations)

(b) Non crossovers   50%   (i) AB   25%
    (Parental   (ii) ab   25%
    combinations)

The above results are possible only if these genes are located far apart in the chromosome so as to exhibit independent assortment providing cent-

percent opportunity for crossing over to occur. In case the genes that are placed closer, the chances of their separation become less. Consequently in the offsprings there is preponderance of parental combinations. In extreme cases the two genes can be so close together that they do not exhibit crossing over.

Frequency of Recombinations Or Percentage of Recombination

The frequency of crossing over or recombination of any two genes is the probable number of crossovers formed between them. It is directly
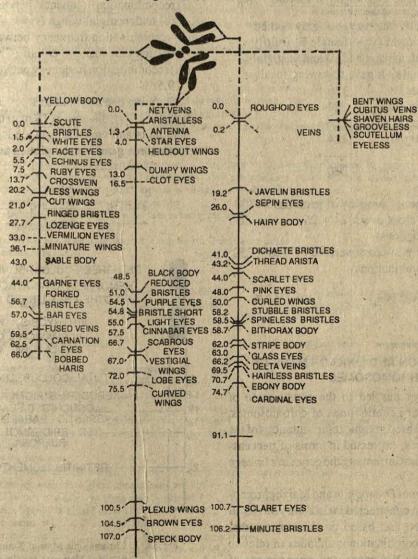
Fig. 32.6 Chromosome maps of *Drosophila*

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proportional to the distance between the two genes. Frequency of crossing over is used as an index of relative distances between the genes on a chromosome.

The frequency of crossing over or the **percentage of recombination can be determined** –
(i) by counting the number of chiasmata formed during deplotene of the prophase I under the microscope.
(ii) by conducting controlled experiments and calculating the frequencies of parental and recombinant types of offsprings.

Frequency of recombination =
$$\frac{\text{No. of recombinants in the progeny of test cross}}{\text{Total no. of progeny of the test cross}} \times 100$$

Example. A fully heterozygous gray bodied (b+), normal winged (vg+) female F$_1$ fruitfly was crossed with a black bodied and vestigial winged (bvg) male. It gave following results :

(i) Grey, normal	126
(ii) Grey, vestiginal	24
(iii) black, normal	26
(iv) black, vestigial	124

Total	300

In this example-
(i) Total number of progeny of testcross = 300
(ii) Number of cross overs 24 + 26 = 50
(new combinations)
(iii) Number of non-crossovers 124 + 126 = 250
(parental combinations)

Percentage of crossing over = $\dfrac{50}{300} \times 100 = 16.7\ \%$

or
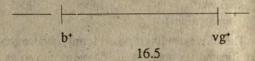
Frequency of crossing over

RECOMBINATION AND LINKAGE MAPS OF CHROMOSOMES

Crossing over has led to the construction of **linkage maps** or **genetic maps** of chromosomes, which are condensed graphic representations of the relative distances, expressed in terms of **percentage of recombination** among the genes in a linkage group.

Linkage maps of *Drosophila* and Maize chromosomes have been constructed in details by MORGAN and STURTEVANT and based on the concept that frequency of recombination is an index of relative distance between the genes, the arrangement of
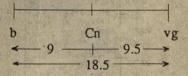
genes on the chromosomes has been plotted. 1% crossing over between two genes represents one unit distance between them. In the example discussed the percentage of crossing over between grey body colour and normal wings/or black body and vestigial wings is 16.7%. It means the distance between these genes is 16.7 units which can be represented as follows.

b$^+$ vg$^+$

16.5

Say in *Drosophila.*
(i) recombination frequency between black body (b) and vestigial wings (vg) is – 18%
(ii) recombination frequency between black body (b) and cinnabar eye colour (Cn) – 9%
(iii) recombination frequency between vg and Cn – 9.5 %

Defining one map unit as 1 per cent recombination, the b - vg distance is 18 map units, b - cn is 9 map units and vg - cn distance is 9.5 map units. These three genes can be plotted as shown below:

b   Cn   vg
← 9 — + — 9.5 →
← 18.5 →

RED GREEN COLOURBLINDNESS
HEMOPHILIA, OTIC ATROPHY
AND OTHER SEX-LINKED GENES

ICHTHYOSIS, HYSTRIX
GRAVIOR & OTHER
HOLANDRIC GENES

9	- - - - -TOTAL COLOURBLINDNESS-	9
14	- - - -XERODERMS PIGMENTOSUM-	14
17	- - - -OGUCHI'S DISEASE-	17
18	- - - - -SPASTIC PARAPLEGIA-	18
20	- - - -REC. EPIDERMOLYSIS -	20
	BULBOSA	
28	- - - -RETINITIS PIGMENTOSUM-	28
		Y
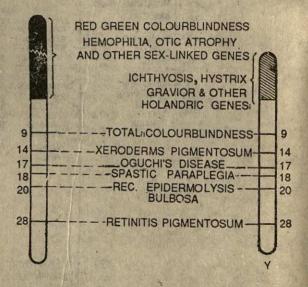
Fig.32.7   Chromosome Map of X and Y chromosomes of Man with sex linked genes

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On an average, one map unit corresponds chromosome in which crossing over will occur once in fifty meiotic divisions. For short distances the map units are additive but not for long distances because multiple crossing over may occur within long distances. These will after and lower % of crossing over and consequantly under estimate the actual genetic distance between genes.

QUESTIONS

1. Explain linkage in brief. Mention how it differs from Mendel's law of independent assortment ?
2. Describe the process of linkage. Give its significance.
3. What do you understand by sex-linked inheritance ? Name two sex-linked chracters of man. Illustrate the inheritance of one of them.
4. What is criss-cross inheritance ? Explain with a suitable example.
5. How it can be proved that genes are arranged in a linear fashion ?
6. Why certain characters like baldness, diabetes etc., are more frequent in man than in woman ? Illustrate your answer with one suitable example.
7. What do you understand by crossing over ? What part does it play in the heredity ?
8. Discuss the evidence to prove that crossing over occurs at the fourstrand stage and not at two strand stage.
9. What is linkage map or chromosome map ? How does crossing over frequency or percentage of recombination help in gene mapping ?
10. Discuss the significance of study of *Neurospora crassa* in understanding mechanism of crossing over.
11. A heterozygous grey-bodied, normal winged *drosophila* female of F1 was test crossed with a black bodied, vestigial-winged male. The cross gave the following results :
    (i) Grey normal - 40   (ii) Grey vestigial - 10   (iii) Black normal - 10   (iv) Black vestigial - 40
    Ascertain whether this indicates linkage and calculate the percentage of crossing overs.
12. What are advantages of test cross method for determining linkage relation ?
13. If the linkage strength between two gene loci is 70 percent, what would be the amount of crossing over between them ?
14. What is coupling and repulsion ?
15. How the relative distance between two gene loci is determined ?
16. Trace the interrelationship that exsits between frequency of crossing over and the distance between the genes.
17. *Drosophila melanogaster* has 6 chromosomes and man has 46. How many linkage groups are there in each case ?
18. List the type of gametes produced from female Drosophila whose genotype is AB/ab.
    (i) if there is no crossing over between these genes and   (ii) if these genes undergo crossing over?
19. What do you mean by strength of linkage ? What factors influence this?
20. What is criss-cross inheritance ?
21. What is sex-linkage? What role does Y-chromosome play in sex-linked inheritance ?
22. Why a haemophilic female is rare ?
23. Summarize significance of crossing over ?
24. Explain the following:
    (a) Linkage maps   (b) Chromosome theory   (c) Coupling and repulsion
    (d) Cis and trans arrangement   (e) Parental combinations   (f) Recombination
    (g) Skip-generation.
25. Differentiate between the following:
    (a) Holandric genes and digenic genes   (b) Homozygous and homogametic
    (c) Linkage and sex-linkage   (d) Linkage and crossing over
26. Why is *Drosophila* used for conducting genetic expreiments ?
27. Why percentage of crossing over is always less than 50 percent ?
28. What do you understand by the following terms :
    (i) Homogametic sex   (ii) Map unit   (iii) Frequency of crossing over   (iv) Chiasmata
    (v) Homologous chromosomes   (vi) Coupling   (vii) Autosomes   (viii) Linkage groups   (ix) Carrier.
29. A woman has normal colour vision but her father was colourblind. If she is married to a colourblind person, what are the chances of colourblind children ?
30. Complete the following sentences :
    (i) The chances of recombination between two gene loci are inversely *proportional to the* ....
    (ii) All the genes which occur in a given chromosome are known as ....
    (iii) If testcross offsprings of a dihybrid cross show a ratio of 1 : 1 : 1 : 1, it means the genes are ....
    (iv) Recombination of genes is caused as a result of .... between chromatids of homologous chromosomes.
    (v) Crossing over occurs at ....stage of meiosis.
    (vi) Crossing over involves .... between homologous chromosomes.
    (vii) Daughters of a colourblind man and a normal woman will all be ....
    (viii) The grandson of a haemophilic male will have .... percent haemophilics.
    (ix) Crossing over percentage can never exceed ....percent.

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Sex - Determination and Sex-Linkage

Sex behaves as a Mendelian character. Its inheritance follows law of segregation. In majority of diploid sexually reproducing animals, the chromosomes are of two types -

1. **Autosomes** that carry genes for body characters and general physiology.
2. **Sex chromosomes** that carry genes for determining the sex.

Usually animals possess one pair of sex-chromosomes. These are represented by **X** and **Y**. **X**-chromosome possesses genes that determine development of female sex and **Y** chromosome is male determining.

SEX-DETERMINATION IN DROSOPHILA

In *Drosophila* the total number of chromosomes is eight, of which six are **autosomes** common to both males and females. The fourth pair is of sex-chromosomes. In males these are represented by **XY**. The karyotype of male *Drosophila* is represented by **6+XY**. In females sex chromosomes are **XX** and their karyotype is represented by **6+XX**. Ova produced by female are all similar having **3+X** chromosomes whereas sperms produced by male are of two types with **3+X** and **3+Y** chromosomes. The male Sex is described as **heterogametic** as it produces two types of gametes (3+x and 3+y). The female sex is **homogametic** as it produces ova only of one type *i.e.* 3+x.

MALE	**FEMALE**
(Heterogametic Sex)	(Homogametic Sex)
XY	XX

Sperm < X / Y

X / X > Ova

	Ova	
	X	X
X	XX	XX
Y	XY	XY

XX — female —50%

XY — male — 50%

Fig. 33.1 Sex-determination in man.

SEX DETERMINATION IN MAN

In case of man total number of chromosomes is 23 pairs or 46. **Man is heterogametic**, while **woman is homogametic**.

In male (man)	44 + XY
In female (woman)	44 + XX.

The **sperm** produced by male are of two types (i) 22+X, (ii) 22+Y, whereas the **ova** all have 22+X chromosomes.
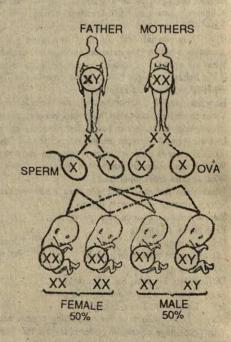
Fig. 33.2 Sex-determination in man. Note that all the eggs carry X-chromosome but one-half of the sperm carry an X-chromosome and one-half carry a Y-chromosome.

Role of X and Y-chromosomes

In man X-chromosome is female determining and Y-chromosome is male determining.

Sex anomalies found in human race support the role of X- and Y- chromosome in determining sex in human beings.

1. **Klinefelter's syndrome (2n = 47 or**

44+XXY). This is caused by the presence of an extra X-chromosome in males. Such males possess 47 chromosomes (44 autosomes+XXY sex chromosomes). Morphologically, these are sterile males with under-developed genitalia, sparse body hair and some degree of breast development. These exhibit mental retardation and limited intelligence. Klinefelter's syndrome is seen in one out of every 500 male births. It arises by the nondisjunction of XX-chromosomes.

2. **Turner's syndrome (2n = 45 or 44+X).** It is caused by the absence of one X-chromosome in
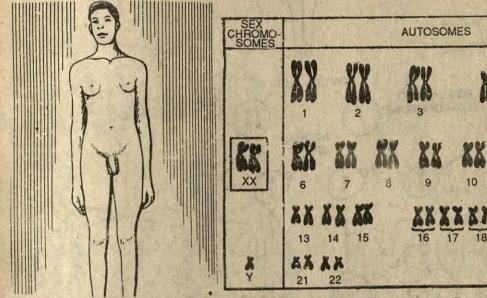
Fig. 33.3A - A person showing Klinefelter's syndrome.

Fig. 33.3B Chromosome compliment of a person suffering from Klinefelter's syndrome.
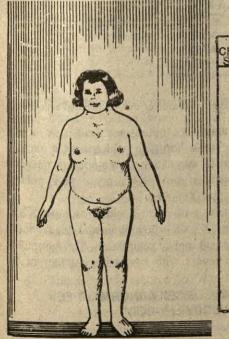
Fig. 33.4A. A woman showing Turner's syndrome.
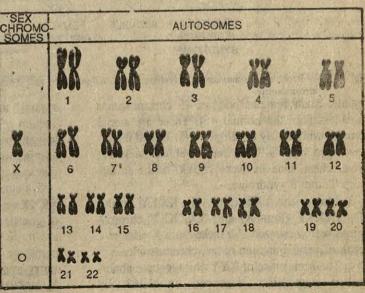
Fig. 33.4B. Chromosomes compliment of a woman suffering from Turner's syndrome.
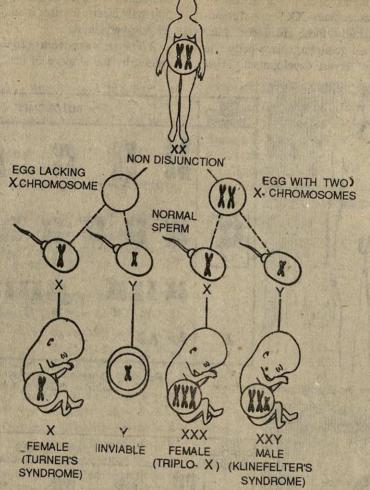
Fig. 33.5 Probable mechanism of development of Klinefelter's and Turner's syndromes due to nondisjunction of X chromosome.

female. Such females possess 45 chromosomes (one less than the normal 46). These are sterile females with poorly developed ovaries and under-developed breasts. They have webbed neck and broad chest. One in every 25,000 births suffers from Turner's syndrome.

3. Males with **XXY** (diplo X), **XXXY** (triplo-X), **XXXXY** (tetra X) and **XXXXXY** chromosomes were observed. All these extra X arise as a result of nondisjunction of sex-chromosomes.

4. The occurrence of **XYY** chromosome abnormality was first observed in 1962 by T.H. HAUSCHKA. The extra Y-chromosome is strongly male determining and leads to overproduction of male hormone, which causes unusual height, mental retardation, over aggressiveness and criminal bent of mind. XYY genotype is present one in every 300 males.

5. Females with extra X-chromosomes (**XXX, XXXX** or **XXXXX**) show abnormal development of gonads and mental retardation. The symptoms are more severe with increasing number of X-chromosomes.

DETECTION OF SEX ABNORMALTIES by BARR BODY or Y-BODY

The sex and sex-syndromes in man can be

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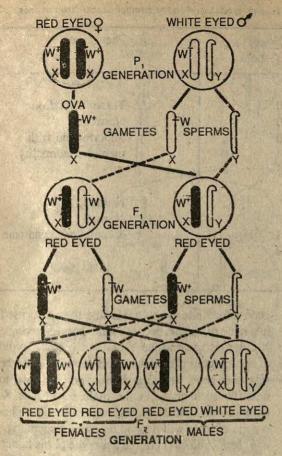
Fig. 33.6 **Sex-linked inheritance in** *Drosophila melanogaster.* Note the transmission of sex-chromosome carrying eye colour gene W+ and w in a cross between red eyed female and white eyed male.

Fig. 33.7 **Sex-linked inheritance in** *Drosophila.* Note the transmission of sex-chromosomes carrying eye colour gene W+ and w in a cross between white eyed female and red eyed male.

2. The white-eyed female possesses gene for white eye colour (w) on both of its X-chromosomes. It transmits one gene for white eye colour (w) to each offspring.

3. The white-eyed males receive X-chromosome with w gene from the mother and Y-chromosome with no such gene from father. Therefore, recessive w gene in hemizygous state (*i.e.* represented singly) produces white eye colour in all the male offsprings.

4 The daughters receive one X-chromosome with w gene from mother and one X-chromosome with dominant W-gene for red eye colour from father. Therefore, all of them are red-eyed phenotypically but ge-

netically they are heterozygous (W+w)

SEX LINKAGE IN MAN

Although nearly 20 sex-linked genes are known in man, the most common example are -

1. Red green colourblindness
2. Haemophilia
3. Diabetes

1. Red Green Colourblindness - Some persons are unable to distinguish certain colours. They are called **colourblind.** Several types of colourblindness are known but the **red green colourblindness** is most common. It was described by HORNER (1876). It is a sex-linked recessive character whose gene is located on X-chromosome.

(i) When a normal woman is married to a colour-

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	Sex Chromosomes	No. of Barr bodies	No. of Y-spots	Phenotypes
	Female			
1.	XO	0	0	Turner's syndrome
2.	XX	1	0	Normal
3.	XXX	2	0	Superfemale with mental abnormality
			1	
	Male			
1.	XY	0		Normal
2.	XYY	0	2	Normal
3.	XXY	1	1	Klinefelter's syndrome
4.	XXYY	1	2	"

determine the somatic or body chracteristics. *Such body characters whose genes are located on sex-chromosomes and follow sex during inheritance are known as* **sex-linked** *characters*. The genes governing them are **sex-linked genes** and their inheritance as **sex-linked inheritance** or **sex-linkage**.

SEX-LINKAGE IN DROSOPHILA

Sex-linkage was discovered by THOMAS H. MORGAN (1910) while working on *Drosophila melanogaster*. MORGAN noted the sudden appearance of one white-eyed male in the culture of wild red-eyed *Drosophila*. This white-eyed male was mated with red-eyed females. the F_1 flies (both male and female) were all red-eyed, indicating that white eye mutation (w) is recessive to red eye colour (W^+). when F_1 flies mated freely the red and white-eyed flies appeared in the ratio of 3 : 1. But all white eyed flies were male. The red eyed and white eyed males were in 1 : 1 ratio in the progeny. The females were all red-eyed. In this cross white-eyed females did not appear.

MORGAN concluded that the gene for eye colour is located on the X-chromosome. The F_1 red-eyed females were heterozygous (W^+ w) because the red eye colour is dominant. A white-eyed female could appear only when it is homozygous for ww genes *i.e.* both its X-chromosomes possess the recessive gene for white eye colour. On the other hand single

gene w for white eye colour is able to express itself in a male offspring, because male possesses single X-chromosome and the Y-chromosome is devoid of homologous allele which can dominate over the recessive gene. The term **hemizygous** is used to describe such genes in the male sex. Since X-chromosome in male comes from mother, the phenotype of male will depend on mother's genotype and there is no effect of the genotype of his father.

In a reciprocal cross when a red-eyed male was crossed to a white-eyed female, the F_1 offsprings. instead of being all red-eyed consisted of 50% red-eyed and 50% white eyed and all the red-eyed offsprings were females and all the male offsprings were white-eyed. When these F_1 offsprings were interbred, their F_2 offspring consisted of red and white-eyed individuals in equal proportion in both the sexes. In *Drosophila*, therefore, sex-linked traits such as white eye colour follows a criss-cross inheritance. **The male transmits his sex-linked traits to grandsons through his daughters.**

The inheritance of white eye colour in *Drosophila* can be explained by assuming that :
1. Gene for white eye colour is located in the X-chromosome and Y-chromosome is empty carrying no normal allele for white eye colour.
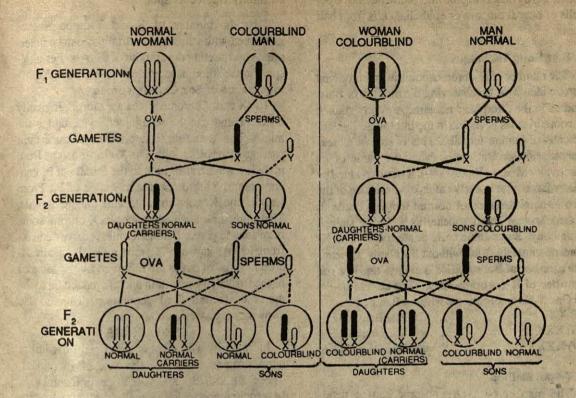
Fig. 33.8 Sex-linked inheritance of colourblindness in a cross between normal woman and colourblind man

Fig. 33.9 Sex-linked inheritance of colourblindness in a cross between colourblind woman and normal man.

Table 33.1 : Showing inheritance of colourblindness

PARENTS				OFFSPRINGS			
Female		Male		Daughters		Sons	
Geno type	Phenotype	Geno type	Phenotype	Geno type	Phenotype	Geno type	Phenotype
1. XX	Normal	X^cY	Colourblind	Xx^c	Carrier	XY	Normal
2. Xx^c	Carrier	XY	Normal	(i) XX	Normal	XY	Normal
				(ii) Xx^c	Carrier	x^cY	Colourblind
3. Xx^c	Carrier	X^cY	Colourblind	(i) Xx^c	Carrier	XY	Normal
				(ii) x^cx^c	Colourblind	x^cY	Colourblind
4. X^cx^c	Colourblind	XY	Normal	x^cX	Carrier	x^cY	Colourblind

blind man, their offsprings (daughters and sons) have normal colour vision. But when these daughters are married to normal men 50% of their sons are colorblind and the remaining 50%

identified by observing the interphase nucleus from cells of buccal mucosa or epithelial cells from hair roots.

1. Barr Body Technique

The number of X-chromosomes in an individual can be identified by observing the number of Barr-bodies in the interphase nucleus. A darkly stained chromatin mass is visible in the interphase nucleus of cells of human females. This is known as **sex-chromation** or **Bar-body** (after the name of its discoverer MURRAY BARR, 1949). It was explained by MARY LYON that in early embryogenesis one of the two X-chromosomes of normal females becomes heterochromatic and appears as a darkly stained Barr body. Since male cells possess only one X-chromosome, these are without Barr body. It means **the number of Barr bodies is always one less the number of X-chromosomes.** Thus cell with -

(i) One X-chromosome are without Barr body
(ii) XX   „   „ with one Barr body
(iii) XXX   „   „ with two Barr bodies
(iv) XXXX   „   „ with three Barr bodies

2. Y-spot Method

The number of Y-chromosome can be determined in the interphase nucleus because Y-chromosome has a fluorescent spot on its long arm. If the cells are stained with quinacrine dyes and are viewed under ultraviolet light, this spot appears as a brightly fluorecent spot.

Thus the number of X-and Y-chromosomes associated with various abnormalities can be determined by counting the number of Barr-bodies or Y-spots in the interphase nucleus (see table 27.2)

Inheritance of Sex Chromosomes

The X and Y chromosomes are morphologically different and can be recognized even under the microscope. therefore, it is possible to trace their passage in the offsprings. The X-chromosome from male is always transmitted to the female of F_1 generation and Y-chromosome to males of F_1. From female one X goes to male and one to female. Therefore, male always receives its X-chromosome from female parent but the female receives one X, from female and one X from male. It means X-chromosome of males are inherited by the females of the first filial generation and are passed on to the males of second filial generation. This is also known as **criss-cross inheritance.**

SEX-LINKAGE
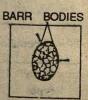
In majority of animals a pair of dissimilar chromosomes determine the sex of individual. These are called **XX – XY chromosomes** or **heterochromosomes.** Usually individuals with **XX-chromosomes** are female and with **XY-chromosomes are males** (as in Drosophila, man etc.) In addition to male and female-determining genes, these sex chromosomes also carry a few genes that

BARR BODIES
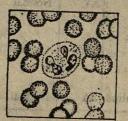
NORMAL MALE

NORMAL FEMALE

KLINEPELTER SYNDROME

DRUMSTICK

NORMAL FEMALE

NORMAL MALE

Fig 33.9 Recognition of sex in man by Barr body

A — Nucleus of normal male with no Barr body.
B — Nucleus of normal female with one Barr body. (*i.e.*, XX chromosomes)
C — Nucleus of triploid female with two Barr bodies (*i.e.* with XXX-chromosome).
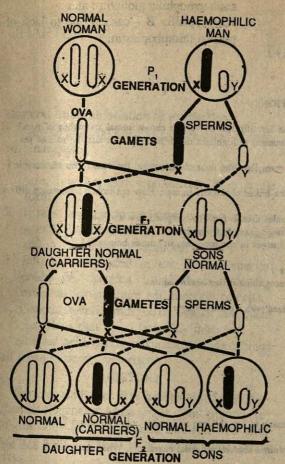
Fig. 33.10 Sex-linked inheritance of haemophilia in a cross between normal woman and haemophilic man.

are normal, while daughters are all normal.

(ii) When a colourblind woman is married to a normal man, their daughters are normal but all the sons are colourblind. When these F_1 daughters are married to colourblind men, colourblind sons and daughters are produced in equal number.

2. **Haemophilia** (Bleeder's disease) - This disease in man is restricted entirely to male members. In hemophilic men the blood fails to clot. Even a small skin injury results in continuous bleeding and may lead to death from loss of blood. In normal man it takes 2 -8 minutes for blood to clot.

Hemophilia is caused by sex-linked recessive gene located in the X-chromosome, which fails to produce a factor necessary for quick clotting. Its inheritance shows -

(i) **Haemophilic man** (if survived) and married to a normal woman produces daughters all carriers (normal but carrying gene for hemophilia on one of its X-chromosomes). Such a carrier daughter when married to normal man transmits the haemophilic gene to half of her sons (i.e. 50% grandsons of a hemophilic male are haemophilic). A haemophilic woman is produced only if a carrier woman is married to a haemophilic man.

Haemophilic females are very rare because a girl with severe bleeding would die by the time she reaches adolescence. Also chances of homozygous

Table 33.2 : Showing Inheritance of sex-linked character - Haemophilia

	PARENTS				OFFSPRINGS			
	Female		Male		Daughters		Sons	
	Genotype	Phenotype	Genotype	Phenotype	Genotype	Phenotype	Genotype	Phenotype
1.	XX	Normal	X^hY	Haemophilic	XX^a	Carrier	XY	Normal
2.	XX^h	Carrier	XY	Normal	(i) XX (ii) XX^h	Normal Carrier	(i) XY (ii) X^aY	Normal Haemophilic
3.	XX^h	Carrier	X^aY	Haemophilic	(i) XX^h (ii) X^hX^h	Carrier Haemophilic	(i) XY (ii) X^hY	Normal Haemophilic
4.	X^hX	Haemophilic	XY	Normal	X^aX	Carrier	X^hY	Haemophilic

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girl being born in random mating are very rare.

Haemophilia is of two types -

(i) **Haemophilia A** - caused due to lack of antihaemophilic globulin ; and

(ii) **Haemophilia B** - caused due to lack of plasma thromboplastin.

QUESTIONS

1. What is karyotype ? How the study of karyotype helps in the identification of various chromosomal anomalies in man ?
2. Draw karyotype of human male (man) and human female (woman) to highlight the differences. Discuss the role of sex-chromosomes in the determination of sex of a child.
3. Name a few of the common chromosomal abnormalities in man. Describe their chromosomal basis and their phenotypic characters.
4. What do you mean by sex-linked inheritance ? Name two sex-linked characters in man. How sex-linked inheritance differs from autosomal inheritance ?
5. 'A recessive mutation has more chances of experession in males than in females'. Explain how and why ?
6. Explain the mechanism of sex-linked inheritance with a suitable example from man.
7. Discuss various syndromes known to be due to numerical changes in chromosomes in human beings.
8. What is Lyon's hypothesis ?
9. Explain how sex-chromatin helps in the identification of sex ?
10. Give two examples where Lyon's hypothesis helps in the recognition of sex-abnormalities.
11. What is sex-chromatin ?
12. What happens when an egg with XX chromosomes is fertilized with a normal sperm ?
13. How do you identify Turner's syndrome ?
14. Write short notes on:
    (i) Down syndrome
    (ii) Klinefelter's syndrome
    (iii) Turner's syndrome
    (iv) Barr body
    (v) Y-spots
    (vi) Sex-linked abnormalities in man.
15. If a normal woman is married to a colourblind man, how many of her children will exibit colourblindness ?
16. Who discovered Barr bodies and in which year ?
17. A man has poorly developed breast, webbed neck and faminized secondary sexual characters. What abnormality does it exibit and what is its reason ?
18. The nucleus from buccal epithelium cells of a person has a barr body but he is a male. How do you account for this ?
19. A person suffering from Klinefelter's syndrome will exibit how many barr bodies and flourescent Y-spots ?
20. Fill in the blanks:
    (i) In human karyotype the chromosomes of a pair which are dissimilar in male and female are the ....
    (ii) Autosomal abnormality in man which was first reported in 1866 is called ....
    (iii) Colourblindness in man is an example of genetic abnormality due to ....
    (iv) When a woman carrier for colourblindness is married to a colourblind man, her sons will be ....

Nucleic Acids of Genetic Material

General Charachteristics or Properties

Genetic material must fulfill a number of basic requirements -

1. It must contain the information for cell structure, function and reproduction in a stable form.
2. It must be able to replicate to pass on same genetic informations in the descendent cells and in successive generations.
3. Informations coded in the genetic material could be decoded to produce molecules essential for structure and function of cells.
4. Genetic material must be capable of infrequent variations that could be stably inherited.

Nucleic acid (Deoxyribonucleic acid) exhibits all these basic characteristics.

HISTORY

Nucleic acid was first isolated by Swiss biochemist FRIEDRICH MIESCHER in 1869 from nuclei of pus cells and was named **nuclein**. The term **nucleic acid** was used to denote its acidic property.

IDENTIFICATION OF GENETIC MATERIAL

The chromosomes are hereditary vehicles. Chemically, these are formed of **proteins** and **nucleic acids**. On account of their structural complexity proteins were considered to be the hereditary material for a very long time, until experiments proved that nucleic acid (DNA) is the hereditary material. These are:

1. Bacterial Transformation
2. Bacteriophage infection

1. Bacterial Transformation or Griffith Effect

(A) FREDRICH GRIFFITH, a bacteriologist of England in (1928) found that pneumonia causing bacteria - *Diplococcus penumoniae* occurs in two strains -

(1) **Virulent Strain (S-III)** - The pneumococcal cells of virulent strain cause pneumonia when injected because its cells are enclosed in a polysaccharide capasule, which protects them from being engulfed by W.B. Cs. Because of capsulated cells, the colony has glistening appearance and is called as **smooth.**

(2) **Avirulent Strain** (R-II) - The pneumococcal cells of this strain do not produce symptoms of pneumonia because these lack a polysaccharide capsule and are destroyed by W.B. Cs. Their colonies have irregular appearance and are known as rough (R).

GRIFFITH in experiment injected these bacteria in mice and made the following observations -

(a) R-II (nonvirulent) bacteria were injected in mice – mice suffered no illness.
(b) S-III (virulent, bacteria were injected in mice – mice developed pneumonia and died.
(c) S-III (virulent) bacteria were heated to 600C and killed. These heat-killed bacteria were injected in mice No pneumonia symptoms.
(d) A mixture of R-II) nonvirulent and heat-killed S-III bacteria were injected into mice - the mice developed pneumonia and died.
(e) Bacteria isolated from these dead mice were found to contain a mixture of capsulated (S-III) and non-capculated (R-II) forms.

GRIFFITH concluded that presence of heat-killed S-III bacteria has caused transformation of some R-II bacteria into virulent, capsulated S-III bacteria. This was described 'Griffith effect' or bacterial transformation.

(B) Three scientists AVERY, MACLEOD and McCATHY (1944) separated and identified the chemical which transformed the non-virulent forms to virulent forms. This was confirmed to be DNA. A culture of *Pneumococci* nonvirulent type R-II was grown in the petridish containing - agar and the microbiological culture medium. The capsulated bacteria of virulent strain type S-III were
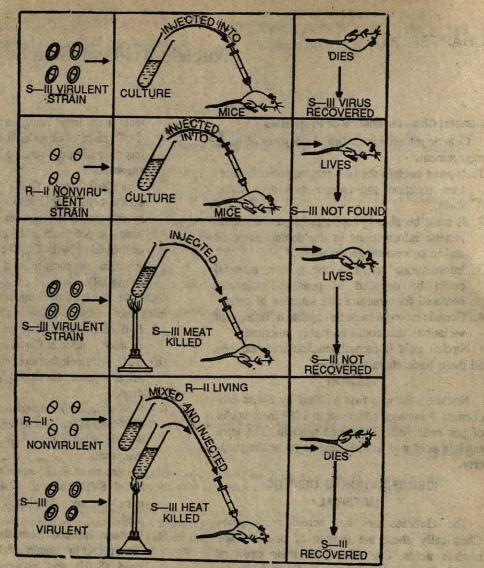
Fig. 34.1 Griffith's experiment to demonstrate genetic transformation in Pneumococcus bacteria.

then ground finely or heat killed and were added to the nutrient medium. After few hours, the new culture of bacteria contained a mixture of virulent S-III and non-virulent R-II bacteria. It means some R-II bacteria were transformed into S-III bacteria. This phenomenon of transferring characters of one strain to another by using a DNA extract of former is known as **transformation.** When this extract was treated with DNAase (DNA hydrolysing enzyme) the transforming property of extract is lost. But when treated with protesaes (the protein hydrolysing enzymes) the transform-

ing ability was not lost.

Thus this experiment shows that,

1. Hereditary material (DNA) can be extracted from one organism and can be introduced into another to modify its hereditary material.

2. The gene is DNA.

3. Evidence form Bacteriophage Infection

DNA is the carrier of genetic informations is shown by the study of viruses which infect bacteria. These are known as **bacteriophage or phage.**

A bacteriophage consists of a head and a tail. The head is formed of protein coat which encloses a DNA-core. Tail is formed of protein only.

common bacterium *Escherichia coli*, to demonstrate that its DNA carries the genetic informations.
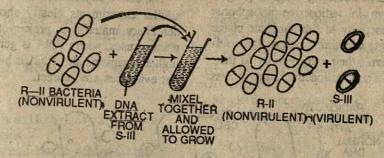
Fig. 34.2 Genetic transformation in pneumococcus in vitro using extract from S-III heat killed virulent bacteria.

The phage attaches itself to the bacterial cell by its tail. The DNA present inside the head is transferred into the bacterium, whereas the protein coat is left outside. Inside the bacterial cell the phage-DNA duplicates and produces large number of new phage-DNA molecules. Each of these DNA-molecules develops it own protein coat forming daughter phage particles.

A.D. HERSHEY and M.J. CHASE (1952) conducted experiments on T$_2$-phage, a parasite on

(i) Some phages were grown in bacteria containing radioactive sulphur-S^{35}. Sulphur is incorporated in the formation of amino acids. These radioactive amino acids formed the protein of the phage.

(ii) Some other phages were grown in bacteria containing radioactive phosphorus - P^{32}. Phosphorus is an important constituent of DNA. Therefore, radioactivity in these bacteriophages was restricted to DNA.
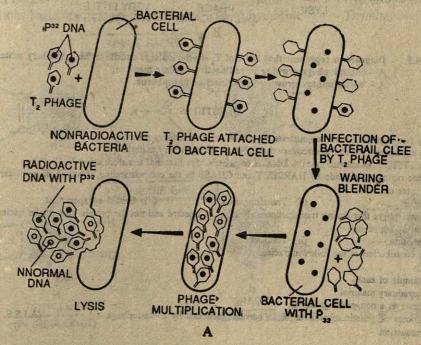
Fig. 34.3 Diagram to represent that DNA of T$_2$-bacteriophage constitutes the hereditary material.

These two types of radioactive phages were made to infect normal bacteria in two separate samples. About 20 minutes after the infection, the bacteria cells ruptured liberating daughter phages. The phages grown in radioactive phosphorus passed their radioactivity to the daughter phage particles. The phages containing radioactive sulphur did not transmit their radioactivity to their daughter phages. Their radioactive sulphur was found in the remains of bacteriophages (the protein coat left outside the bacterial cells).

Gene Is DNA

The above experiments and a number of other similar experiments clearly show that DNA is hereditary material in prokaryotes except some plant viruses, where RNA is genetic material. In higher organisms also DNA is hereditary material but evidences are indirect.
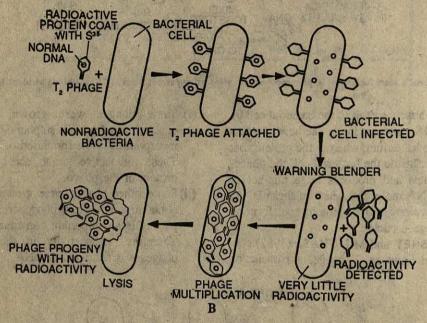
Fig. 34.5   Diagram to represent that DNA of T₂-bacteriophage consitute the hereditary material.
A – bacteriophage growing in radioactive sulphur medium;
A – bacteriophage growing in radioactive phosphorus.

QUESTIONS

1. Describe any two experiments to demonstrate that DNA is the hereditary material.
2. Which basic experiment led to the discovery that DNA is the hereditary material ?
3. How did GRIFFITH demonstrate that the DNA is responsible for bacterial transformation ?
4. Summarize the contribution made by HARSHEY and CHASE in the underdstanding of nature of hereditary material.
5. Write short notes on—
   (i) Transduction   (ii) Transformation   (iii) Griffith's experiment
6. How would you prove that during transduction only DNA is injected and not the protein coat of the bacteriophage ?
7. Define the following terms—
   (i) Transformation   (ii) Transduction
8. Mention the contribution of the following scientists—
   (i) F. Griffith
9. Give one example of each—
   (i) RNA is hereditary material
   (ii) DNA occurs as a nongenetic material.
10. Name the process of genetic recombination in bacteria mediated by bacteriophage   (A.I.S.S. Exam. 1986)
   Hint :– Transduction.

Nucleic Acids

There are two types of nucleic acids -

1. **Deoxyribonucleic acid - DNA -** localized in nuclei.

2. **Ribonuleic acid - RNA -** found largely in cytoplasm.

Importance

Nucleic acids (DNA and RNA) play an essential role in protein synthesis.

1. DNA contains information needed for protein synthesis.

2. RNA allow synthesis to be carried out.

STRUCTURE

Nucleic acids (DNA + RNA) are very long linear **polymeric macromolecules**. Nucleotide is their monomeric unit. It is **deoxyribonucleotide** in DNA and **ribonucleotide** in RNA. Each nucleotide is formed of a nitrogenous base, a pentose sugar and a molecule of **phosphoric acid.**

1. **Pentose Sugar**

It is **deoxyribose** in DNA and **ribose** in RNA. Both are pentose monosaccharides.

2. **Nitrogenous Bases**

The nitrogenous bases are nitrogen containing organic ring compounds. These are of two types -

(A) Two ringed compounds - **Purines**

  (i) **Adenine** represented by   **A**

  (ii) **Guanine**   ,,   ,,   **G**

(B) Single ring compounds - **Pyrimidines**

  (iii) **Thymine**   ,,   ,,   **T**

                  (present only in DNA)

  (iv) **Cytosine**   ,,   ,,   and   **C**

  (v) **Uracil**   ,,   ,,   **U**

                  (present only in RNA)

Nucleosides

A nitrogenous base with a molecule of deoxyribose or ribose (without phosphate group) is known as **nucleoside**. The pentose and base are joined by a β - **osidic bond**, formed between semialdehyde OH^- group of monosaccharide at 1 and H of pyrimidine base (at 1) or the purine base (at 9) carbon atom of the ring. In all , there are four nucleosides in a DNA molecule. These are -

1. **Adenosine**   - Adenine + Deoxyribose

2. **Guanosine**   - Guanine + Deoxyribose

3. **Cytidine**   - Cytosine + Deoxyribose

4. **Thymidine**   - Thymine + Deoxyribose.
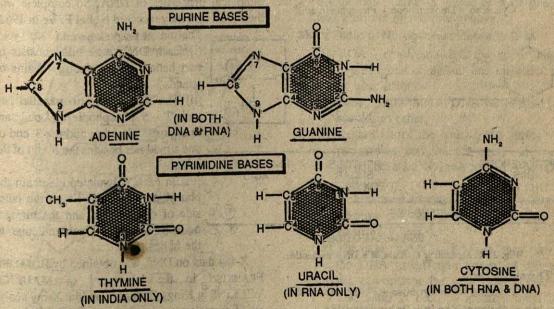
Fig. 35.1 Structural formulae of purines and pyrimidines found in nucleic acid.
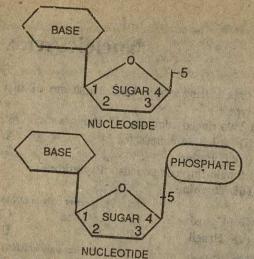
Fig. 35.2 Diagrammatic representation of nucleoside and nucleotide

Nucleotides

A **nucleotide** is formed of one molecule of deoxyribose, one molecule of phosphoric acid and one of the four nitrogenous bases. Since there are four nitrogenous bases, there are four types of nucleotides namely :

1. Adenylic Acid
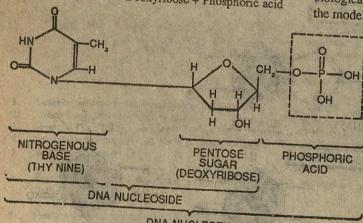
    - Adenine+ Deoxyribose + Phosphoric acid

2. Guanylic acid

    - Guanine + Deoxyribose + Phosphoric acid

3. Cytidylic acid

    - Cytosine + Deoxyribose + Phosphoric acid

Fig. 35.4 Structural formula of a DNA nucleotide.

3. Thymidylic acid

    - Thymine + Deoxyribose + Phosphoric acid

Linking of Nulceotides in a Polynucleotide chain

In a DNA molecule several thousand nucleotides are linked together to form a **polynucleotide chain**. The nucleotides are called **monomeres** or building blocks. The adjacent nucleotides are connected together by **phosphodiester bond** in which the phosphate group on carbon 5' of pentose of one nucleotide is linked to the 3' hydroxyl group on 3' carbon of pentose of next nucleotide.

Thus the backbone of a polynucleotide chain is formed of alternating phosphate and pentose sugar molecules. One end of this polynucleotide chain has a sugar residue with C-3 carbon atom not linked to other nucleotide and the other end with sugar residue with C-5 carbon also not linked. Thus ends of polynucleotide chain are marked 3' end and 5' end respectively.

1.DEOXYRIBONUCLEIC ACID -DNA

Occurrence. DNA is found in the cells of all living organisms except in plant viruses. In eukaryotic cells it is confined to the nucleus, where in association with proteins it forms **nucleoproteins** or the **chromatin material.** In prokaryotes DNA lies naked and free in the cytoplasm in the nucleiod region.

Watson and Crick's Model of DNA

(Molecular structure of DNA)

Based on X-ray diffraction, WATSON and CRICK in 1953 proposed double helical model of DNA which explains all chemical, physical and biological properties of DNA. So complete was the model that they received **Nobel Prize** in 1962.

The model proposes -

(i) Each DNA molecule consists of two helical polynucleotide chains or strands.

(ii) The stands run **anti-parallel** i.e., their 3' - 5' phosphodiester bonds are in opposite direction and the 3' end of one strand lies besides the 5' end of the other.

(iii) In each polynucleotide chain the phosphate molecules lie on the outer side of deoxyribose and the nitrogenous bases inward, perpendicular to the helical axis.

X-ray data on DNA was obtained by ROSALIND FRANKLIN in the laboratory of MAURICE WILKINS at Kings College, London. X-ray analysis of crystals provides three dimensional organization of macromolecules. X-ray photographs of DNA showed it have helical structure and the
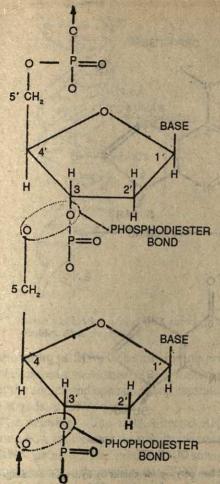
Fig. 35.4 Linking of two nucleotides in a polynucleo-
tide chain of DNA through phosphodiester
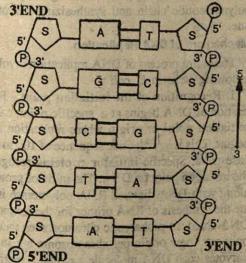
Fig. 35.5 A part of DNA molecule showing the two
antiparallel polynucleotide chains.

width of helix was found to be 2nm.

LINUS PAULING who received **Nobel Prize**
for unravelling helical structure of proteins,
thought that DNA had 3 strands.

(iv) The nitrogenous bases of two strands are
linked through **hydrogen bonds** between oxy-
gen and nitrogen atoms of the adjacent bases.
Since there is fixed distance between the two
strands (11.0 Å or 10.8 Å), only specific base
pairs can fit into the space. Therefore, the base
pairing is very specific.

   (a) A **purine** (2 ringed) always pairs with a
   pyrimidine (one ringed), and

   (b) **Adenine** pairs with **thymine** and **guanine**
   pairs with **cytosine**.

(v) There are two hydrogen bonds between A ≡ T
and three between G ≡ C.

(vi) The two strands are, therefore, complemen-
tary.

(vii) In a DNA molecule the two complementary
chains are twisted around each other and form
a double helix around a common central axis.

(viii) One turn of helix measures about 34 Å and
contains 10 nucleotides.

(ix) Therefore, the distance between the adjacent
nucleotides is 3.4 Å or 0.34 nm.

(x) The diameter of the helix is about 20 Å. The
double helix shows a **major or wide groove**
and a **minor or narrow groove.**

Molar Ratio of Nitrogenous Bases in DNA

CHARGAFF et. al. studied base composition of
DNA from different organisms and arrived at the
following conclusions -

   (i) Base composition of DNA varies from one
   species to other.

   (ii) Regardless of the source, the purine and
   pyrimidine components occur in equal
   amounts in a DNA molecule i.e., A+G =
   C+T.

   (iii) The amount of **adenine** is equivalent to
   thymine (A=T) and of **cytosine** to
   guanine (C = G).

   (iv) The base ratio of A+T : G+C may vary in
   the DNA of different groups of animals
   but is constant for a particular species.
   This ratio is used to identify the DNA
   source.

Fig. 35.6 Diagram to show linking between the nucleotides of two polypeptide chains by hydrogen bonding.

DNA REPLICATION

During replication the weak hydrogen bonds between the nitrogenous bases of the nucleotides separated so that the two polynucleotide chains of DNA also separate and uncoil. The chains thus separated are complementary to one another. Because of the specificity of base pairing, each nucleotide of separated chains attracts its complementary nucleotide from the cell cytoplasm. Once the nucleotides are attached by their hydrogen bonds, their sugar radicals unite through their phosphate components, completing the formation of a new polynucleotide chain.

Thus each chain of the double helix of DNA serves as a template or model on which its complementary chain is built.

This method of DNA replication is described as semiconservative method, because each daughter DNA molecule is a hybrid conserving one parental polynucleotide chain and synthesizing the other one.

Mechanism of DNA Replication

The entire process of DNA replication involves following steps in *E. coli* :

1. **Recognition of the initiation point** - Replication of DNA begins at a specific point, called **initiation point or origin** where replication fork begins. This is a nucleotide sequence of 100 to 200 base pairs. Specific **initiator proteins** recognise the initiation point on DNA. The initiator proteins along with DNA directed RNA polymerase initiate the synthesis of RNA primer for the formation DNA chain. In prokaryotic chromosomes there is only one new origin per chromosome but in eukaryotes each DNA molecule has many (perhaps over a thousand) origins or replication forks.
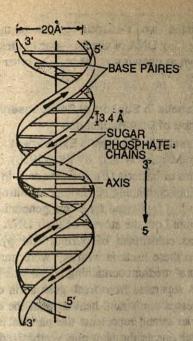
Fig. 35.7 Watson and Erick model of DNA showing double helical structure.

Fig. 35.8 Diagram to show DNA replication.

2. **Unwinding of DNA** - The **unwinding proteins** or helicases or swivelases, bind to the nicked strand of the duplex and open up a loop separating the two strands of DNA duplex.

3. **RNA priming** - The DNA directed RNA polymerase now synthesizes the primer strands of RNA (**RNA primer**). The primer RNA strands are complementary to the two strands of DNA and are formed of 50 to 100 nucleotides. Enzyme **primase** brings above polymerization of RNA primer.

4. **Formation of DNA on RNA Primers** - The new strands of DNA are formed in the 5' - 3' direction from the 3' - 5' template DNA by the addition of deoxyribonucleotides to the 3' end of primer RNA. The addition is affected by DNA polymerase in the presence of ATP. The unwinding proteins separate the duplex strands ahead of the replication fork.

The **leading strand** of DNA is synthesized in 5' - 3' direction as one piece. The **lagging strand of DNA** is synthesized in its opposite direction in
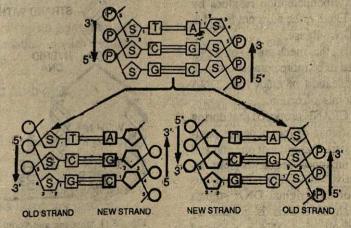
Fig. 35.9 Replication of DNA molecule. The two stands of DNA separate and each of them synthesizes its counterpart, thereby forming two similar molecules of DNA.

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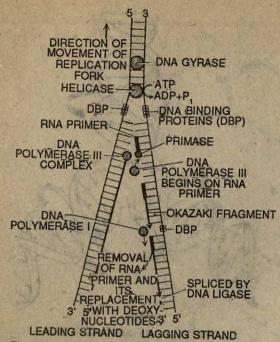
Fig. 35.11 Summary of the major steps in DNA replication

Labels in figure: DIRECTION OF MOVEMENT OF REPLICATION FORK; HELICASE; DBP; RNA PRIMER; DNA POLYMERASE III COMPLEX; DNA POLYMERASE I; REMOVAL OF RNA PRIMER AND ITS REPLACEMENT WITH DEOXY-NUCLEOTIDES; LEADING STRAND; DNA GYRASE; ATP; ADP+P$_1$; DNA BINDING PROTEINS (DBP); PRIMASE; DNA POLYMERASE III BEGINS ON RNA PRIMER; OKAZAKI FRAGMENT; DBP; SPLICED BY DNA LIGASE; LAGGING STRAND

short segments consisting of 1,000 to 2,000 nucleotides. These segments are called **Okazaki fragments.**

5. Excision of RNA primers - Once a small segment of an Okazaki fragment has been formed, the nucleotides of RNA primer are removed from the 5' end one by one by the action of 5' - 3' **exonuclease** activity of DNA polymerase-I.

6. Joining of Okazaki fragments - The gaps left between Okazaki fragments are filled with complementary deoxyribonucleotide residues by DNA polymerase -I. Finally, the adjacent 5' and 3' ends are joined by **DNA-ligase.**

In eukaryotic cells, the mechanism of DNA replication is expected to be more complex than in prokaryotes. The replication of eukaryotic DNA begins at multiple points of origin.

LEVINTHAL and CRANE proposed that during replication the two strands do not separate completely; instead they start unzipping at one end and simultaneously the unzipped segments start attracting their respective nucleotide pairs. In this way the unzipping of the original DNA strands and synthesis of fresh DNA strands go side by side. It means in a duplicating DNA a Y-shaped growing point must be visible. CAIRNS has dem-

onstrated two Y-shaped regions in the circular replicating DNA of viruses—one of these points is known as **growing point** and the other **initiation point.**

Evidences in Support of Semiconservative Method of DNA Replication

1. Meselson and Stahl's Experiment

(i) MESELSON and STAHL (1958) cultured a species of bacteria (*Escherichia coli*) in a cultural medium containing N^{15} isotope of nitrogen. After these had replicated for a few generations in that medium both the strands of their DNA contained N^{15} as constituent of purines and pyrimidines. When these bacteria with N^{15} were transferred in cultural medium containing N^{14}, it was found that DNA separated from fresh generation of bacteria possesses one strand heavier than the other. The heavier strand represents the parental strand and lighter one is the new one synthesized from the culture indicating semiconservative method of DNA replication (Fig. 35.11).

Labels in figure: DNA WITH N^{15}; STRAND WITH N^{14}; STRAND WITH N^{15}; HYBRID DNA; WITH N^{15}; WITH N^{14} HYBRID DNA; LIGHT DNA WITH N^{14}; HYBRID DNA
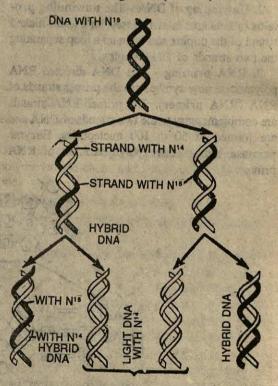
Fig. 35.11 Meselson and Stahl's Experiment to demonstrate semi-conservative method of DNA replication.

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HEAVY. ISOTOPE OF. HYDROGEN
H^3 NORMAL HYDROGEN H^2
H_2 NORMAL HYDROGEN*
CHROMOSOMES WITH DIFFERENT RADIOACTIVITY

DISTRIBUTION OF RADIOACTIVITY IN DNA MOLECULES OF CHROMOSOMES
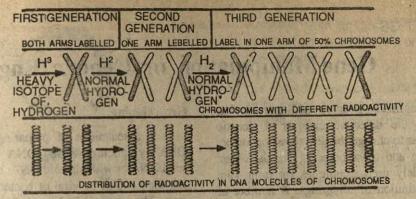
Fig. 35.12 Taylor's experiment on *Vicia faba* root tips using autoradiographic method.

2. Taylor's Experiment on *Vicia faba* Root tips

J. H. TAYLOR (1957), and his coworkers also demonstrated the semiconservative method of DNA replication in the root tip cells of *Vicia faba* by **autoradiography**. The roots were grown in a medium containing radioactive thymidine, so that the radioactivity is incorporated in the DNA of these cells. The outline of this labelled chromosome on a photographic film appears in the form of scattered black dots of silver grains. When these root tips with labelled chromosomes were transferred to the unlabelled medium containing **colchicine*** and studied for radioactivity, the following observations were made :

1. In the chromosomes of first generation the radioactivity was found to be uniformly distributed in both the chromatids, because in them the original strand of DNA double helix was labelled with radioactivity and the new one was nonlabelled.
2. In the chromosomes of second generation only one of the two chromatids in each chromosome was radioactive.

RIBONUCLEIC ACID (RNA)

Occurrence

RNA is synthesized in the nucleus but is found chiefly in the nucleolus and cytoplasm. Inside the cytoplasm it occurs freely as well as in the ribosomes. It helps in protein synthesis but in some plant viruses RNA acts as hereditary material.

Structure

The structure of RNA can be easily understood by comparing it with the structure of DNA.

(i) RNA is a single-stranded structure consisting of a single polynucleotide chain, but it is often folded back on itself forming helices. DNA is a double stranded structure.

(ii) RNA like DNA is formed of several hundreds or thousands of nucleotides arranged in a linear sequence and connected together by 3' - 5' **phosphodiester bonds.**

(iii) The sugar found in RNA nucleotides is **ribose** whereas it is deoxyribose in DNA. The nucleotides of RNA are ribonucleotides.

(iv) The four nitrogenous bases found in RNA are **adenine, cytosine, guanine and uracil,** whereas those in DNA are adenine, cytosine, guanine and thymine. Therefore, thymine of DNA is substituted by uracil in RNA.

(v) The base composition of RNA does not agree to the A/U= G/T = I as it is found in DNA.

(vi) Intramolecular pairing between the nucleotides of the single strand of RNA provides stability to RNA. In DNA nucleotides of two strands of DNA pair through hydrogen bonds.

(vii) DNA is the hereditary material, whereas RNAs are of there different types performing different functions during proteins synthesis.

(a) **Messenger RNA (mRNA)** - It carries genetic informations from chromosomal DNA to the cytoplasm where it acts as a template for protein synthesis. It is complementary to DNA and carries the same base sequence as found in that part of DNA.

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* Colchicine is a drug, which when added to the culture medium prevents cell division but it does not impair chromosome duplication. As a result, the chromosomes which had divided into daughter chromatids accumulate in the original cell.

Gene Manipulation or Genetic Engineering

Genetic engineering aims at adding, removing or repairing the defective cistrons of genetic material, so as to change the defective phenotype. Hybridization and cross breeding are the oldest and still widely used techniques for improving genetic constitution of offsprings. A number of methods and techniques have been developed during recent years which are used to manipulate the genetic material in simple organisms. These include -

1. Recombinant DNA technique or DNA technology.
2. Somatic cell hybridization.
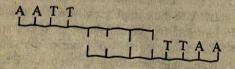
Recombinant DNA Technology

The recombinant DNA technology also known as gene cloning or gene splicing offers ways of introducing any piece or desired piece of DNA into a heterologous organism. This technique developed because of two major discoveries:

1. Discovery of restriction endonuclease enzymes
2. Development of methods of gene cloning.

Restriction endonucleases

The restriction endonucleases are basically elaborated by bacteria as a protection against the entry of foreign (viral) DNA. These enzymes cut or cleave DNA molecules at specific sites (restriction sites) into fragments containing identifiable genes. Many of them are specific for specific palindromes. (Palindromes are base pair sequences that read the same forward or backward such as the word Madam.) In such cases the ends

A A T T
T T A A

of cleaved DNA molecule will be

Gene cloning

It is a technique of preparing recombinant DNA by splicing cleaved DNA molecules with viral DNA or with plasmid DNA, and then obtaining their copies by viral or bacterial multiplication. The copies of cleaved DNA obtained by multiplication of recombinant DNA form cloned DNA (cDNA).

Mechanism of Recombinant DNA Technique

It involves following steps in a series -

1. Random or specific segments of eukaryotic
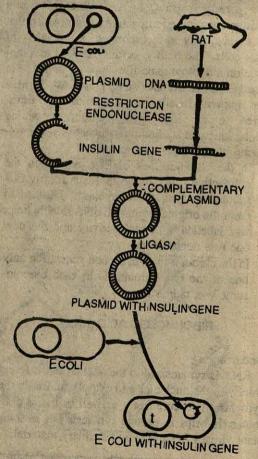
Fig. 36.1 Steps involved in the transfer of insulin gene from rat to E. coli.
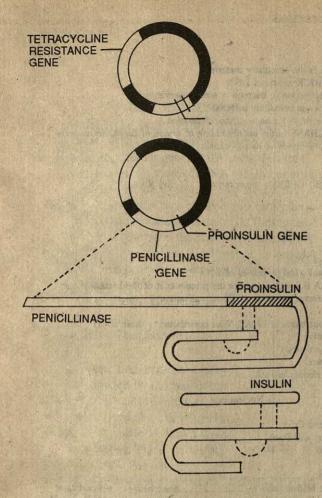
Fig.36.2 Stepwise procedure of recombinant DNA technique.

DNA (even human DNA) are isolated by using **restriction endonucleases**. An entire genome on an organism can be cut into smaller DNA fragments containing one or a few genes.

2. These cleaved DNA segments are joined to another DNA molecule, which serves as a vector. Enzyme **ligases** are responsible for such splicing. The vector facilitates manipulation and recognition of newly created **recombinant DNA molecule**. Bacterial plasmids or **phages** are used as vectors.

3. Vector with recombinant DNA is introduced into the bacterial cell.

4. Within the bacterial cell, the recombinant DNA molecule replicates along with en-dogenous DNA of host cell and produces copies of cloned DNA. This process is called **gene cloning**.

5. The cloned recombinant DNA produced in abundance in an overnight bacterial culture is isolated, purified and analyzed.

6. Potentially, the cloned DNA may be transcribed, its mRNA translated and gene products isolated and studied.

APPLICATIONS OF GENETIC ENGINEERING

1. **Gene structure and expression** - Originally recombinant DNA techniques were developed to unravel the structure and mechanism of expression of genes. Several eukaryotic genes have now been cloned and their DNA sequence determined. It has evolved the concept of **exons** and **introns** present in the eukaryotic genes. Genetic engineering has helped in understanding the mechanism of gene activation. The genome is found to have **structural DNA segments** (cistrons) whose activity is controlled by **regulatory DNA - segments**. Regulatory genes are repress or genes and activator genes or promoters, enhancers, silencers etc.

2. **Industrial and Medical use** - An important application of recombinant DNA technique is the production of medically important products such as **insulin, somatostatin, thymsin** etc. in bacterial cells ; or vaccines and even for diagnostic purposes.
In industry, the recombinant DNA technique is used in the synthesis of certain enzymes required in processing agricultural products and synthesis of many substances or manufacture of bulk chemicals like methanol, ethanol and acetone.

3. **Agricultural application** - This technique can be used in improving genotypes of many crop plants.

1. Describe any two experiments to demonstrate that DNA is the hereditary material.
2. Enumerate the important postulates of WATSON and CRICK model of DNA.
3. Give some experimental evidence to prove that DNA replication in bacteria is semiconservative.
4. Which basic experiment led to the discovery that DNA is the hereditary material ?
5. How did GRIFFITH demonstrated that the DNA is responsible for bacterial transformation ?
6. Summarize the contribution made by HARSHEY and CHASE in the understanding of nature of hereditary material.
7. Write a short account of the structure of DNA and give the mode of its replication.
8. Enumerate difference between DNA and RNA.
9. Write short notes on:
   (i) Transduction   (ii) Transformation   (iii) Griffith's experiment   (iv) RNA.
10. Differentiate between:
    (i) Nucleoside and nucleotide.
    (ii) Purine ring and pyrimidine ring.
    (iii) Ribose and deoxyribose.
11. Name the chemical building blocks of DNA ?
12. Give one evidence in favour of double helical structure of DNA.
13. How does double helical structure of DNA explain the biological properties of DNA ?
14. How would you prove that during transduction only DNA is injected and not the protein coat of the bacteriophage ?
15. Summarise Taylor's experiment to demonstrate semiconservative nature of DNA replication.
16. Give differences between DNA and RNA.
17. What facts you known about the molar ratio of nitrogenous bases in DNA ? Who contributed to these facts?
18. How was it proved that DNA replication is semiconservative ?
19. Name different types of RNA and their role in protein synthesis.
20. Give an example of basic proteins present in chromosomes.
21. Name the nitrogenous base which is present only in the ribonucleic acid.
22. Define the following terms:
    (i) Transformation   (ii) Transduction   (iii) Nucleotide.
23. Mention the contributions of the following scientists:
    (i)   F. Griffith   (ii)   Watson and Crick.
    (iii) Harshey and Chase   (iv)   Messeleon and Stahl
    (v)   Cairnes   (vi)   Chargaff.
24. Fill in the blanks:
    (i) Nucleic acids are macromolecules and polymers of...
    (ii) Two polynucleotide chains of a DNA molecule are held together by.........................bond between paired bases.
    (iii) The nucleotides of a polynucleotide chain are held together by.........................bond between.....................and phosphate group.
25. Give two main important differences between DNA and RNA.
26. What is the basic difference between mRNA and tRNA ?
27. What is a polycistronic RNA ?
28. Give one example of each:
    (i) RNA is hereditary material.
    (ii) DNA occurs as a nongenetic material.
29. What is the diameter of a double DNA helix ?
30. What is the difference between major and minor coils in DNA ?
31. What is the distance between successive nucleotides along a polynucleotide chain ?
32. What is molar ratio ?
33. How many nucleotides are present in a single coil of DNA ?
34. Explain the statement "the two strands of DNA are antiparallel."

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Gene Expression

GENE EXPRESSION

Chemically, a gene is a segment of DNA or a specific sequence of nitrogenous bases. The base sequence in different genes is different. Functionally, a gene is a segment of DNA which controls the cellular function by controlling the synthesis of a protein that acts as a catalyst and catalyses a specific chemical reaction of the cell. These reactions, in turn, determine the phenotypic characters (structural, physiological, biochemical or behavioural). Thus a gene expresses itself in a protein or enzyme that controls the development of a specific character or a specific function.

1. One Gene One Enzyme Theory

'One gene one enzyme' theory was propounded by the geneticists BEADLE and TATUM, while working on red mold *Neurospora crassa* (for which they were awarded **Nobel Prize in 1958**). According to this theory *each gene in an organism controls the production of a specific enzyme.*

The normal strain of *Neurospora* is able to grow in the minimal medium containing sucrose, salts and one of the vitamins biotin (B). It can synthesize all other complex substances, like proteins and nucleic acids from the simple substances of the culture medium. These biochemical synthetic reactions are brought about by specific enzymes.

BEADLE and TATUM exposed some of the asexual spores of *Neurospora crassa* to mutagen (ultraviolet rays). These mutated ascospores were found unable to grow in the minimal medium, but required the addition of **thiamine** for the normal growth.

The controlled experiments by BEADLE and TATUM have shown that manufacture of thiamine from simple substances of minimal medium is completed in a number of steps and each step requires the presence of a specific enzyme and each enzyme is produced by a separate gene.

Let us presume that the synthesis of this vitamin involves ten chemical reactions and each one of them is governed by a specific enzyme. S_1 represent the raw material from the medium, S_{11} is the final product (thiamine) and S_2, S_3 .... S_{10} are the intermediate products the enzymes involved during this process are represented as ε_1, ε_2 ....ε_{10} and genes synthesizing these enzymes G_1 to G_{10}. The entire process of synthesis of thiamine can be represented as follows :
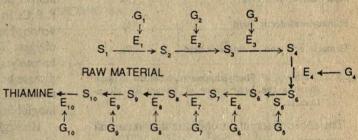
Fig 37.1 Diagrammatic representation of one gene one enzyme theory.

By adding intermediate compounds (precursors) to the medium, BEADLE and TATUM were able to locate that particular step in thiamine synthesis which was blocked in the mutant strain resulting in the absence of a specific enzyme. On this basis they presented **'one gene one enzyme theory'**.

Biochemical Genetics

One gene one enzyme theory of BEADLE and TATUM has laid down the foundation of **biochemical genetics**. It has helped in explaining some of the human hereditary diseases described by ARCHIBALD GARROD (1908) as **'inborn errors of metabolism'**. These are :

1. **Alcaptonuria.** The urine of persons suffering from hereditary disease alcaptonuria turns black on exposure to air due to the presence of a substance **alcapton** (homogentisic acid) in their urine. In normal persons metabolism of

aminoacid **phenylalanine** requires six different enzymes which catalyse six different steps of this pathway as shown in Fig. 37.2. The end products enter Krebs cycle to release CO_2 and water. In alkaptonurics the enzyme **homogentisic acid-oxidase** required in the **conversion of homogentisic acid into maleylacetoacetic acid** is absent. Thus homogentistic acid is passed out in the urine, and latter turns black on exposure to air.

Phenylalanine   (1)
⇓
Tyrosine   (2)
⇓
p-hydroxyphenyl pyruvate   (3)
⇓
Homogentisic acid   (4)
⇓
Maleylacetoacetic acid   (5)
⇓
Fumarylacetoacetic acid   (6)
⇓
Fumaric acid and Acetoacetic acid (7)

Fig. 37.2. Pathway of Phenylalanine metabolism in man showing the basic cause of disease of alcaptonuria.

The above observations indicate that in normal persons, the gene which controls the production of enzyme homogentistic acid-oxidase fails to synthesize the necessary enzyme in alcaptnurics.
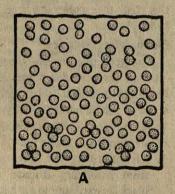
2. **Phenylketonuria** (PKU) – This disease is caused by the absence of the enzyme which catalyses the first step in the metabolism of **phenylalanine.** As a result, phenylalanine accumulates in the blood. This causes mental retardation, pale skin and a tendency to epileptic seizure.

2. One Gene One Polypeptide Theory

Recent studies on the structure of proteins have shown that some of the proteins are formed of more than one polypeptide chains. This has led to the concept of **'one gene one polypeptide theory'.** According to this concept one gene controls the synthesis of one polypeptide chain and not of the complete enzyme or protein molecule. Scientists (Biochemists) have used the term **cistron** for a functional segment of DNA that controls synthesis of one polypeptide chain or codes for one *t*RNA or *m*RNA.

The one gene one polypeptide theory can be illustrated by **'sickle-cell anemia'** a disease of human beings, found specially in Negroes. The R.B.Cs in this disease become **sickle-shaped** in venous blood owing to the lower concentration of oxygen. This causes rupture of cells and severe haemolytic anemia. The molecular basis for the disease lies in the difference of one amino-acid in two of the four chains of protein **globulin** of haemoglobin.

Hemoglobin is a compound of **heme** and **globulin.** It is formed of about 600 amino acids. These amino acids are arranged in four polypeptide chains, two identical α-**chains** and two identical ß-**chains.** The sickle-shaped hemoglobin **(Hb-S)** differs from normal hemoglobin **(Hb-A)** in the presence of **valine** in place of **glutamic acid** in peptide number-seven of the ß-chain (see Fig. 37.4).
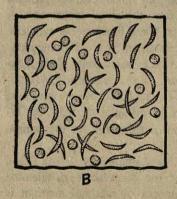
Fig. 37.3. Diagram showing shape of R.B.Cs of human beings in normal (A) and sickle-cell anaemia persons (B).

ß-chain of hemoglobin-A	ß-chain of hemoglobin-S
(1) Valine	Valine (1)
(2) Histidine	Histidine (2)
(3) Leucin	Leucin (3)
(4) Leucin	Leucin (4)
(5) Threonine	Threonine (5)
(6) Proline	Proline (6)
(7) Glutamic acid	Valine (7)
(8) Glutamic acid	Glutamic acid (8)
(9) Lysine	Lysine (9)
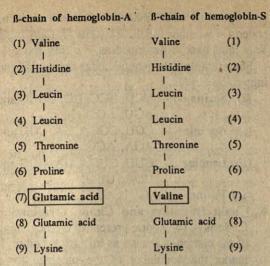
Fig. 37.4. ß-chain of normal hemoglobin and sickle-shaped hemoglobin showing difference in the arrangement of amino acids.

The sickle cell anemia, is therefore, produced by a single change in two ß-polypeptide chains out of the total four. It is caused by a single mutation (change of one codon GAA by GTA in DNA cistron caused by replacement of one nitrogenous base A by T). It means that one gene controls the synthesis of one polypeptide chain.

GENETIC CODE

Genes act by producing enzymes. Enzymes are proteins formed of polypeptide chain of amino acids. The sequence of amino acids in polypeptide chain is determined by sequence of nitrogenous bases in the polynucleotide chain of DNA composing specific gene. F.H.C. CRICK postulated the existence of a **genetic code**. Its smallest unit of three nitrogenous bases that codes for one amino acid of the polypeptide chain is called a **codon**.

A codon (code word) is triplet sequence of

SECOND BASE

FIRST BASE	U	C	A	G	THIRD BASE
U	UUU }Phe UUC UUA }Leu UUG	UCU UCC }Ser UCA UCG	UAU }Tyr UAC UAA } Ochre (terminator) UAG }Amber (terminator)	UGU }Cys UGC UGA Terminator UGG Try	U C A G
C	CUU CUC }Leu CUA CUG	CCU CCC }Pro CCA CCG	CAU }His CAC CAA }Gln CAG	CGU CGC }Arg CGA CGG	U C A G
A	AUU AUC }Ilu AUA AUG } Met	ACU ACC }Thr ACA ACG	AAU }Asn AAC AAA }Iys AAG	AGU }Ser AGC AGA }Arg AGG	U C A G
G	GUU GUC }Val GUA GUG	GCU GCC }Ala GCA GCG	GAU }Asp GAC GAA }Glu GAG	GGU GGC }Gly GGA GGG	U C A G

Fig. 37.5. Triplet codons of *m*RNA for amino acids represented in tabular form.

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nitrogenous bases in mRNA copied from DNA molecule which codes for a particular amino acid; whereas the **genetic code** is the sequence of nitrogenous bases in mRNA molecule, which encloses the information for linking of amino acids during the synthesis of protein molecules.

Triplet Code

Since there are only four nitrogenous bases in mRNA for 20 amino acids, a combination of only one or two nitrogenous based can not provide sufficient code words for 20 amino acids. A **singlet code** consisting of only one nucleotide provides just four codons A, C, G and U. These are insufficient to code for 20 amino acids. A combination of two nitrogenous bases (**doublet code**) provide 4 ×4 = 16 condons still insufficient for 20 amino acids. A combination of three nitrogenous bases will give $4 \times 4 \times 4 = 64$ **codons**, which are more than enough to code for twenty amino acids. The table in Fig. 37.5 provides the list of codons for each amino acid.

Although, informations are coded in the form of nitrogenous base sequence in DNA molecule, it is customary to represent the code letters of mRNA because the message from DNA is carried out in the cytoplasm by mRNA and the code on mRNA is translated into the sequence of amino acids polypeptide chain.

Essential Features of Genetic Code

The genetic code has following special features—

1. **Triplet codon** – A codon comprising of three nitrogenous bases of mRNA in a specific sequence.
2. **Commaless** – There is no punctuation (comma) between the adjacent codons.
3. **Degeneracy of Genetic Code** – Most of the amino acids (except two) can be directed to their specific places in the peptide chain by more than one codons. This multiple system of coding is known as **degenerate system** or **degenerate code** and provides a protection to organisms against many harmful mutations, stabilizes phenotypes by lessening the effect of random mutations and minimizes the consequences of base pairing errors.

The major degeneracy occurs at the third position (3' end of the triplet codon). When first two bases

are specified the same amino acid may be coded for whether the third base is U, C, A or G. This third base is described as **Wobbly base**.

For example note genetic codes for the following amino acids :

(*i*) **Serine** – UCU, UCC, UCA, UCG and AGU, AGC.

(*ii*) **Agrinine** – CGU, CGC, CGA, CGG and AGA, AGG.

(*iii*) **Leucine** – CUU, CUC, CUA, CUG and UUA, UUG.

(*iv*) **Valine** – GUU, GUC, GUA, GUG.

4. **Chain Initiation and Chain Termination Codons** – The codon present in the beginning of the cistron is known as **initiation codon**. It marks the beginning of the message for a polypeptide chain. The initiation codon is AUG in majority of cases and it codes for amino acid methionine.

Similarly, the last codon of a cistron helps in reading the termination of polypeptide chain. This is known as **termination codon**. There are three termination codons - UAA, UGA and UAG. Earlier when the function of these codons was not known, these were called nonsense codons.

The initiator and terminator codons are known as signals and this phenomenon is known as **punctuation**. Punctuation helps in delimiting the different cistrons on a polycistronic mRNA.

Discovery of Genetic Code or Cracking of Genetic Code

The existence of a triplet code was proved by NIRENBERG (Noble Prize winner) and MATHAEI in 1961. They were able to synthesize artificial mRNA which contained molecules of only one base uracil. It was named as **polyuridylic (poly-U) molecule**. The synthetic poly-U was placed in a cell-free system containing protein-synthesizing enzymes, all the twenty amino acids and necessary ATP. After some time a small protein-like molecule was produced which was formed by the linking of phenylalanine. It means UUU is the codon for phenylalanine.

Similarly, poly-A mRNA gives **polylysine-peptide** chain and poly-C gives **polyproline**. Therefore, codon-AAA was assigned for lysine and CCC to proline.

PROTEIN SYNTHESIS

1.Transcription of m RNA

The process of synthesis of different types of RNA under the direction of DNA is known as **transcription**. In presence of enzyme **DNA-dependent RNA polymerase**, the DNA directs the synthesis of mRNA in the same way as it guides its own duplication. The two stands of DNA uncoil and separate locally to expose a particular cistron and one of them, the **master strand** acts as a template from which exact sequence of nitrogenous bases is copied into the mRNA by the assembly of ribonucleotides. During transcription, for every cytosine (C) in the DNA molecule, a guanine (G) is inserted in the mRNA strand and similarly every G picks up C ; T picks up A and every A picks up U (uracil) because there is no thymine in mRNA. This mRNA is complementary to DNA in base sequence and is taped with message for the synthesis of a specific protein. It comes out into the cytoplasm to get attached to a ribosome.

2. Activation of Amino Acid

In the cytoplasm amino acids are present in inactive state and must be activated before these can join to tRNA. The enzyme **amino acyl synthetase** catalyzes the reaction of union of amino acid and ATP to form a complex **amino-acyl adenosine monophosphate** or **aminoacyl adenylate (AMP ~ AA)**.

(i)   Amino-acid + ATP + Enzyme   → Amino-acyl AMP – Enzyme + PP
(pyrophosphate)

(ii)   AMP ~ AA – Enzyme + tRNA   →   AA ~ tRNA + AMP + Enzyme.

3. Attachment of acticated amino acid withith RNA

The enzyme bound activated amino acids (amino aceyl adenylates) attach with their specific tRNA molecules and form **amino acid tRNA complex**. The reaction is catalysed by the same amino acyl synthetase enzyme which catalyses activation of amino acid.

Since a specific amino acid attaches to a specific aminoacyl synthetase and also to a specific tRNA molecule, there must be minimum 20 different enzymes and 20 different types of tRNA molecules in each cell (though these are more than 20).
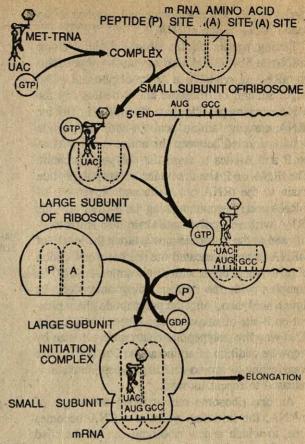
Fig. 37.6 Stages in the formation of initiation complex in eukaryotic cell during protein synthesis.

4. Translation (Assembly of polypeptide chain)

The term translation denotes the process in which sequence of nucleotides in mRNA is translated into the sequence of amino acids of a polypeptide chain. This occurs on the ribosomes. A ribosome attaches to the end of mRNA and serves as a site where three letter codon (**triplet codon**) of mRNA is recognized by the three letter code word (**anticodon**) of a tRNA molecule. Here a tRNA molecule with a specific anticodon and carrying a specific amino acid (AA – tRNA) attaches to the specific codon of mRNA. For example, a tRNA, molecule having anticodon **UAC**

carries amino acid methionine and attaches to the codon AUG on the mRNA.

During translation the ribosome shifts along mRNA in 5' – 3' direction so that the next codon on mRNA is available at A-site of ribosome. The larger subunit of ribosome has two slots one for tRNA carrying peptide chain (P-site) and other for tRNA carrying amino acid (A-site). A peptide bond is formed between the amino acids present on P and A-sites to form the polypeptide chain. The tRNA on P site then transfers its polypeptide chain to the tRNA on A-site and moves out of mRNA and ribosome, making the P-site free. This tRNA with new polypetide chain then shifts to P-site and as the ribosome moves along the length of mRNA its newly vacated site reaches a new codon of mRNA and binds with a new amino-acyl tRNA complex with the corresponding anticodon. Its amino acid then, joins the polypeptide chain present on P-site of ribosome and repeats the process. This way the polypeptide chain grows in size by stepwise addition of amino acids. The tRNA after transferring its amino acid to polypeptide chain is released to repeat its work.

As one ribosome moves along the length of mRNA, the initiation point of mRNA becomes free, to which a new ribosome can get attached and start the synthesis of a new polypeptide chain. Thus during the process of protein synthesis a number of ribosomes may be seen attached to a single mRNA, each with a polypeptide chain of different size.

Termination of Polypeptide Chain

By the time a ribosome reaches the end of mRNA strand its polypeptide chain is complete. With the aid of a releasing factor, the completed polypeptide chain is released and the ribosome is set free, which dissociates into its two subunits.

GENE REGULATION

(Gene Regulation of Enzyme synthesis)

1. Genetic Induction

In a cell, some enzymes are normally present all the time. These are called **constitutive enzymes**. While certain enzymes are synthesized only when these are needed. The synthesis is induced by the presence of specific substance.
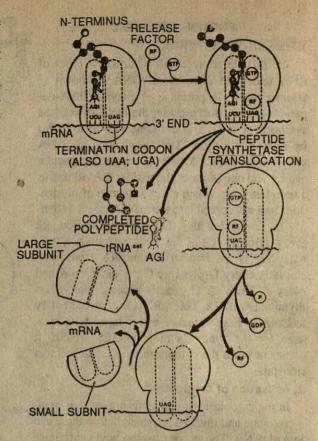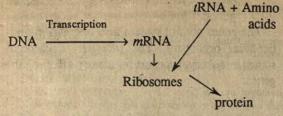
Fig. 37.7 Elongation and release of polypeptide chain in eukaryotic cells.

Such enzymes are called **inducible enzymes**, the substance that induces their synthesis is the **inducer** and the mechanism is **genetic induction**. The synthesis of enzyme is controlled by genes. It has been demonstrated that when intestinal bacteria, *Escherichia coli*, are grown on glucose medium, they contain just traces of ß-galactosidase (an enzyme that hydrolyses lactose into glucose and galactose). If these bacteria are transferred into a medium containing lactose, the concentration of this enzyme increases many fold that enables them to metabolise lactose. Here substrate lactose has acted as an inducer activating the specific gene to synthesize the enzyme in question.

The genes are formed of DNA which contains information for the synthesis of specific proteins in the specific sequence of nucleotides. Thus DNA controls synthesis of proteins as a shown below :

$$\text{DNA} \xrightarrow{\text{Transcription}} m\text{RNA}$$

tRNA + Amino acids

Ribosomes

protein

2. Repression

Presence of certain substances or of a particular end product may suppress the activity of certain genes to synthesize specific enzymes involved in the synthesis of that end product. Such substances are called **repressors** and enzymes as **repressible enzymes.**

Repression is some what similar to feedback inhibition but is different because in repression. The activity of gene is supressed by the end product so that mRNA is not synthesised, while in feed back the enzyme is inactivated by the end product.

The phenomenon of induction and repression depends upon the chemical composition of medium.

The Operon Hypothesis

JACOB and MONOD (1961) suggested that protein synthesis is controlled by induction and repression at transcription level as illustrated in *E. coli* for catabolism of lactose.

Three enzymes are required for lactose catabolism. These are produced by three **structural genes** or DNA segments represented by cistron-Z, cistron-Y and cistron-α.

These structure genes are associated with **control genes.** These include -

2. **Regulator gene** that produces some specific enzyme, the **repressor** which binds to the operator gene and suppresses or shuts off the synthesis of mRNA from operator gene.

3. **Promoter gene** initiates the transcription of structure genes and controls the rate of mRNA synthesis. There are separate promoter genes for regulator and operator genes.

1. In the absence of inducer lactose, the regulator gene produces a repressor protein that binds to the operator gene and prevents the
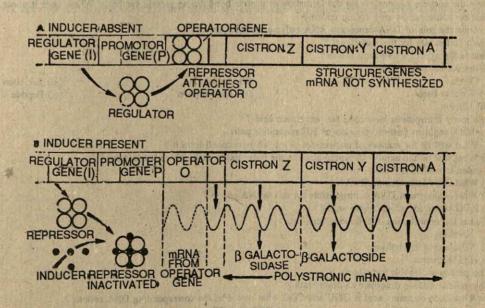
Fig. 37.8 Schematic representation of operon hypothesis to explain gene regulation in lac operon of *E. coli.*

transcription of mRNA from structural genes and protein synthesis is shut off.

2. When inducer lactose is introduced in the medium, it binds to the repressor substance. The repressor fails to binds to the operator. The operator then induces the RNA polymerase to bind to the promotor and to transcribe mRNA by the structure genes.

The genes control system also operates in multicellular organisms. The proteins of chromosomes in eukaryotes exert regulatory effect on the genes.

QUESTIONS

1. Enumerate the various steps involved in protein synthesis.
2. What do you mean by genetic code ? Discuss in brief the special features of genetic code.
3. Explain 'how the sequence of nucleotides in a DNA corresponds to the sequence of amino acids in a specific polypeptide chain which is synthesized under its control ?
4. What is translation ? Explain briefly the role of mRNA and tRNA in the process of translation.
5. Distinguish among mRNA, rRNA and tRNA. What is the role played by each in protein synthesis ? What serves as the template for their synthesis ?
6. What is transcription ? Describe it in brief.
7. Explain that the basic mechanism of mRNA synthesis is the same as that for DNA replication.
8. Discuss the role of mRNA in protein synthesis.
9. Justify the statement 'the triplet code is degenerate'. What is the utility of this speciality of code for living organism ?
10. Outline the essential features of triplet code.
11. Differentiate between transcription and translation.
12. How is mRNA synthesised ?
13. Write short notes on.
    (i) Polyribosomes   (ii) Codon   (iii)   Anticodon
14. What do you mean by punctuation codons in mRNA ? What are their roles ?
15. What experimental evidence proves the existence of triplet code ?
16. Explain the universality of genetic code.
17. Describe the role of ribosomes in protein synthesis.
18. Name the enzyme responsible for the formation of peptide bond during protein synthesis. Where does it occur ?
19. What do you mean by an initation codon ?
20. Describe the role of DNA-dependent RNA polymerase enzyme.
21. Which codon acts for the start signal ?
22. What is the role of termination codon ?
23. Define the following terms:
    (i) Codon   (ii) Anticodon   (iii) Initiation codon
    (iv) Wobbly base   (v) Transcription   (vi) Peptide linkage
    (vii) Cistron.
24. How many nitrogenous base code for one amino acid ?
25. If a DNA segment (cistron) consists of 102 nucleotide pairs -
    (a) What will be the number of nucleotides in mRNA transcribed from it ?
    (b) What will be the number of amino acids in the polypeptide chain which it translates ?
26. A codon in mRNA is AUG -
    (a) What is its anticodon in tRNA?
    (b) What sequence of DNA is responsible for this mRNA codon ?
    (c) AUG codes for which amino acid ?
27. What is the contribution of following scientists -
    (a) Kornberg
    (b) Nirenberg and Mathaei
    (c) H.G. Khorana.
28. Who proposed Wobble hypothesis ?
29. Why genetic code is described as degenerate ?
30. If mRNA code of amino acid is GGU and CGC what would be the corresponding DNA codons ?
    Hint :- (i) GGU → CCA   (ii) CGC → GCG.
31. Only with the help of diagrams and footnotes illustrate the mechanism of protein synthesis.
32. Fill in the blanks :
    (i) The bond between the corboxyl end of one amino acid with the amino group of another is known as.........................
    (ii) One of the codons of RNA for phenylalanine amino acid is.............................

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(*iii*) A DNA segment A-T-C-G-T is transcribed into....................... *m*RNA structure.

33. What are the functions of *m*RNA and *t*RNA ? Which anticodons will be required ton recognize the following codons ?
(*i*) AAU,   (*ii*) CGA,   (*iii*) UAU.

34. Describe operon hypothesis to explain the control of enzyme synthesis at transcription level.

35. Explain with suitable example the phenomenon of competitive inhibition of enzyme action.

36. Discuss in brief the mechanism of genetic regulation of enzyme action. How is regulation of enzyme synthesis brought about?

37. Discuss the following in brief :
(*i*) Allosteric regulation   (*ii*) Operon hypothesis   (*iii*) Genetic induction   (*iv*) Isoenzymes.

38. Name three properties that are common to all enzymes that differentiate them from those of inorganic catalysts.

39. What is competitive inhibition in enzyme action ?

40. Distinguish between isoenzyme and coenzyme.

41. Discuss the role of vitamins to enzyme action .

42. What is allosteric site and active site on an enzyme molecule ?

43. Why enzymes are called 'biocatalysts' ?

44. What is an isoelectric point ?

45. What is the fundamental basis for enzyme classification ?

46. What are constitutive enzymes ?

47. The amino acids in a protein molecule are connected by a specific bond. These bonds are called.................

48. Why enzymes are required in small amount ?

49. What is the biological significance of enzymes ?

50. What is the difference between an enzyme and a catalyst ?

51. Why cold blooded animals undergo hibernation ?
Give one example of isoenzyme.

52. Fill in the blanks :
(*i*)   The enzymes lower the....................so that the biochemical reaction begins at normal atmospheric temperature.
(*ii*)   A coenzyme consists of two parts : a protein part called...............and a nonprotein part if...................
(*iii*)   At a temperature of...............°C, the enzyme action stops because the enzyme becomes....................
(*iv*)   The operon hypothesis was proposed by................and...............in the year.....................
(*v*)   The substance that activates structure genes to produce enzyme for the completion of a metabolic pathway is known as....................
(*vi*)   The accumulation of end product of a series of enzymatic reactions within the cell inhibits the first enzymes of this pathway so as to stop all the reactions of the series. This is known as.......:................

53. What would happen when salivary amylase that acts specifically on starch enters the stomach and mixes with gastric juice.

□ □

Molecular Basis of Differentiation

Differnetiation

The process of development involves the division of fertilized egg into many cells. During early cleavage, the blastomeres are **totipotent**. It means each embryonic cell is able to develop into an embryo and give rise to all tissues of adult organism.

As cell division proceeds, the blastomeres lose versatility. These cells assume different shapes, structures and functions. Collectively these form tissues, organs and organ systems. 'The whole process by which totipotent unspecialized embryonic cells become specialized and give rise to specific tissues is called **differentiation**.'

Differentiation is, therefore, defined 'as the full sequence of changes involved in the progressive diversification of cell structure and function; so that a cell becomes specialized and final product is called **differentiated cell**.

Though differentiation is a cellular event, cells do not differentiate in isolation. It can be described as a communal process that occurs within groups of similar cells.

Types of Difernetiation

All kinds of differentiations are caused by change in the chemical constituents of cell.

1. From **biochemical standpoint** differentiation is the process by which a cell chooses one or a few specialized synthetic pathways. As for example - synthesis of haemoglobin in erythrocytes and certain specific crystalline proteins by the lens.

2. From **functional standpoint** differentiation involves functional specialization such as, development of contractility by muscle fibres or development of conductivity along a nerve fibre or synthesis or **RuBP carboxylase** in leaf cells in plants.

3. From **morphological standpoint** differentiation involves change in shape and structure. (See table 38.1)

Molecular Basis of Differentiation

It is not known what primary events trigger differentiation along a particular pathway. Basically chemical changes are brought about by enzyme action. Any change in enzyme pattern, naturally leads to differentiation.

Enzymes are **acidic proteins**. These control all metabolic pathways of cell activities. Synthesis of these proteins is controlled by nucleic acids. Thus basic structure of all cells is determined by DNA of chromosomes.

Table 38.1: Differences in the characteristics of undifferentiated and differentiated cells

S.No.	Characteristics	Undifferentiated cells	Differentiated cells
1.	Nuclear size	Large	Small
2.	Nucleocytoplasmic ratio	High	Low
3.	Nuclear chromatin	Dispersed	Condensed
4.	Nucleolus	Prominent	Less prominent
5.	Cytoplasmic staining	Basophilic	Acidophilic
6.	Ribosomes	More numerous	Less numerous
7.	Mitotic activity	Great	Reduced or lost
8.	Metabolism	Generalized	Specialized

Role of Nucleus In Differentiation

1. SPEMANN (1928) by classical **dilayed nucleation experiment** established that nuclei remain **totipotent**.

2. ROBERT BRIGGS and THOMAS KING (1952) conducted first **nuclear transplantation experiments** in frogs eggs. They concluded that nuclei remain **totipotent** upto certain stage of development (gastrula in frog) and do not get changed irreversibly in the course of development.

3. FISCBERG and GURDON (1968) transplanted nuclei from differentiated intestinal cells of an amphibian tadpole into enucleated amphibian eggs. A tadpole was not formed. This shows that nuclei undergo some changes during

differentiation.

Upto a particular stage in early embryonic differentiation, the process is reversible. It means to attain totipotency, the differentiated cell has to dedifferentiate. In animals this dedifferentiation is possible only upto early embryonic stages of differentition. Cancer cells form other example of dedifferentiation.

In plants, even a mature differentiated cell can dedifferentiate and form a **callus**. A whole plant can develop from a single cell of this callus. Because of this capability plants can be grown vegetatively from cuttings.

Role of Egg-Cytoplasm During Differentiation

It the nucleus remains totipotent in the undifferentiated embryonic cells and if all of them have identical genetic constitution (clonal cells), how these become different during differentiation ? Presumbly, all genes are not equally active in all the cells, *i.e.* there is differential gene expression in different cell types. Though all have identical genotype. Differential gene expression and differential protein synthesis in cells is controlled at three different levels –

1. **Control on Differentiation at the genome level** caused by chromatin diminution, gene amplification or genetic lesions. There cause decrease or increase in the genetic material.
2. **Control of differentiation during transcription** of *m*RNA caused by heterochromatization (condensation of chromatin) or by enzymes (or acidic proteins).
3. **Control of differentiation at translation level** caused by injuring or regulating functioning of *m*RNA so as to prevent synthesis of new proteins.

Thus, differentiation may be because of alteration or loss of genes resulting in altered gene activity. These changes in gene activity are brought about by the interaction with the environment. Since the immediate environment of the gene is cytoplasm. It forms the microenvironment. It is influenced by a wide variety of parameters such as nutrition, light, temperature, cell-cell interaction. In addition to nuclear - cytoplasmic interaction in differentiation WILDE (1961) and LASH (1968) have shown existence of **intercellular interaction.**

For Example,

1. WILDE demonstrated that a single undifferentiated pigment cell in a hanging drop culture medium never differentiates ; of the two cells in the same medium, only one undergoes differentiation.
2. LASH (1968) has shown that somatic cells under normal conditions differentiate into cartilage at a given time. But if these come in contact with notochord, spinal cord or the extract of these cells, the cartilage cell differentiation occurs faster.

QUESTIONS

1. What do you understand by differentiation ?
2. With the help of two suitable experiments discuss the effect of microenvironment or differentiation.
3. Describe levels of differentiation during embryogenesis.
4. Define — heterochromatization, gene amplification and gene diminution.

☐ ☐

CHAPTER 39

Origin of Life

The origin and evolutionary history of life is a subject of much speculative interpretation. The views put forward from time to time to explain the origin of life are as follows :

1. Theory of Special Creation

According to this view, all the existing plants and animals were created by some supernatural power or God. These forms were designed according to their surroundings and from the beginning till today, they exist unchanged.

2. Theory of Spontaneous Generation or Abiogenesis

Before the end of seventeenth century, both scientists and philosophers believed that living things could arise spontaneously from inanimate substances. For example, insects were believed to arise from dew, frogs and toads from the muddy bottom of ponds, butterflies from cheese and fly maggots from flesh. The idea of spontaneous generation was appreciated by *ARISTOTLE* (384-322 B.C.). *VAN HELMONT* (1652) stated that young mice could arise from wheat grains when these are put in a dark room along with a moist dirty shirt.

3. Theory of Biogenesis (Life from life)

Many scientists disbelieved in abiogenesis. According to them 'Life arises from pre-existing life'

and not from nonliving matter. They established theory of biogenesis.

(1) **Redi's experiment** - Italian physician *FRANCISCO REDI* (1626-1698) demonstrated that maggots could not be created from meat but the smell of meat attracted flies which laid eggs on the flesh. The maggots appeared when eggs hatched. *REDI* placed lumps of boiled meat in jars. Some jars were left uncovered. Some were covered with fine gauze or muslin cloth and others with parchment paper. The meat decayed in all jars but maggots appeared only in the uncovered jars where flies could lay their eggs on meat (Fig. 39.1).

(2) **Spallanzani experiment**-After the study of microbes (protozoa, bacteria etc.) by *LEEUWENHOECK* (1632-1723) English biologist *NEEDHAM*, proposed that if not the complex organisms, at least the primitive unicellular organisms could have arisen from nonliving matter. He boiled mutton gravy, filled it in a corked vial and showed the appearence of living organisms in the gravy after a few days. But in 18th century, *LAZZARO SPALLANZANI* contradicted Needham's observations by conducting following experiment :

Spallanzani poured hay infusion in eight bottles and boiled all of them. Four of them were just corked

Fig. 39.1 Redi's experiment to disapprove theory of spontaneous generation.

and other four were made airtight. After few days he found that there was thick growth of micro-organisms in all the corked bottles but no organisms in the airtigh bottles. He argued that air contains micro-organisms and was the source of contamination.
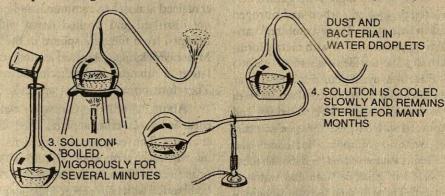
(3) **Pasteur's experiment** - French biochemist *LOUIS PASTEUR* (1864) prepared hay infusion in swan-necked flask as shown in Fig. 39.2. The infusion was boiled to kill the microbes in the infusion and made it sterile. *PASTEUR* reported that such flasks remained free of life for over 18 months. But when the swan-neck was broken and infusion came in contact with air microbes appeared. Thus Pasteur proved that life comes only from pre-existing life.

by *CHARLES DARWIN* in his letter to distinguished Botanist *SIR JOSEPH HOOKER* A detailed theory based on this idea was proposed by Russian biochemist, A. I. *OPARIN* in 1923 and by J. B. S. *HALDANE* in 1928.

According to biochemical theory of origin of life, life originated spontaneously from some nonliving organic compounds in the oceans of primitive earth about 3.1 billion years (3100 million) years ago. Lederberg considered three stages in the origin of life **Chemogeny biogeny** and **Cogmogeny**

Origin of Earth and its Primitive Atmosphere

The earth is presumed to have originated about five billion or six billion years ago either as a part

Fig. 39.2 Louis Pasteur's experiment to disapprove Theory of abiogenesis

1. NUTRIENT SOLUTION ADDED TO FLASK
2. NECK OF FLASK BENT INTO S-SHAPED CURVE USING HEAT
3. SOLUTION BOILED VIGOROUSLY FOR SEVERAL MINUTES
4. SOLUTION IS COOLED SLOWLY AND REMAINS STERILE FOR MANY MONTHS

DUST AND BACTERIA IN WATER DROPLETS

BIOCHEMICAL ORIGIN OF LIFE

This theory finds the widest acceptance. A vague idea that life could have originated on the primordial earth in some warm little ponds, was innovated

broken off from the molten mass of sun (**planetesimal hypothesis**) or by gradual condensation of interstellar dust (**nebular hypothesis**) from which our entire solar system is presumed to be formed.

PRIMITIVE ATMOSPHERE

SHELL   CORE
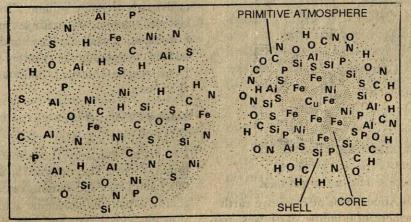
Fig. 39.3 Origin of primitive earth.

Initially, it was a fiery spinning ball of hot gases and vapours of various elements. Gradually, through hundreds of millions of years, the gases condensed into a molten core and different elements got stratified according to their density. The heavy elements like iron and nickel etc. sank to the centre and formed the solid core of the earth, the lighter elements such as silicon, aluminium formed the middle shell, while the lightest ones like helium, hydrogen, oxygen, nitrogen and carbon etc. flowed to the surface and formed the gaseous atmosphere (which ought to have been different from what it is today).

The original temperature of earth is estimated to be 5000-6000⁰ C. At such a high temperature elements like hydrogen, oxygen carbon and nitrogen could not exist in free state. These combined variously either among themselves or with metals forming oxides, carbides and nitrides. As a result carbon was found as dicarbon, cyanogen, methane and as metal carbides. Nitrogen existed in combination with metals to form nitrides, oxygen formed oxides, and hydrogen combined with oxygen, nitrogen and carbon forming water, ammonia, methane and cynamide. The temperature was so high that all these compounds existed in gaseous state and water as superheated steam. These formed the atmosphere of primitive earth.
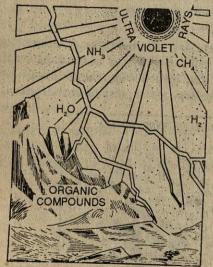
Fig. 39.4 Persumed primitive atmosphere and the sea at that time.

Composition of Atmosphere of Primitive earth

The atmosphere of primitive earth was com-posed of NH_3, CH_4, steam, cyanides, carbon dioxide and free hydrogen. It was without free oxygen. Such an atmosphere is described as reducing type of atmosphere.

As the earth cooled gradually some of the atmospheric gases liquified, and some of the liquids turned into solids. Steam condensed into water and resulted in rain. The rain droplets on approaching the super-heated earth crust immediately evaporated and returned into the atmosphere. This cycle continued for millions of years and resulted in the cooling of earth surface. As a result the earth surface became cool enough to hold water and the large water bodies or first oceans came into existence. The oceanic water contained atmospheric ammonia and methane which got dissolved and washed down with the water, dropped from the atmosphere in the form of rain. Mineral rocks also dissolved leading to the accumulation of minerals and salts in the oceanic water. Therefore, primitive oceans were alkaline (PH-8).

About 3.5 million years ago or afterwards the earth had a solid crust, at places filled with hot boiling sea water. The sea water contained dissolved ammonia, methane, some minerals and salts. The earth's primitive atmosphere was devoid of oxygen. It was bombarded with high energy radiations from the sun.

1. CHEMOGENY (CHEMICAL) ORIGIN OF LIFE

1. Synthesis of Complex Organic Compounds

OPARIN suggested that over a period of time more and more complex organic compounds were formed gradually from methane, ammonia and water about 3.1 billion years ago. The first organic compounds formed were amino acids, simple sugars, lipids, fatty acids, purines and pyrimidines. The energy for such synthetic reactions was available from UV radiations of sunlight, electric discharge and from lightening and high temperature of primitive earth. The ozone free atmosphere enabled radiations to reach earth in abundance.

Stanley Miller and Urey's Experiment

In 1953 STANLEY MILLER and HAROLD UREY recreated in the laboratory, the probable conditions on primitive earth. They designed an apparatus of glass tubes and flasks and demonstrated that simple organic compounds, like amino acids, hydroxy acids, aliphatic acids, sugars and urea etc. can be synthe-

sized in the laboratory when a mixture of methane, hydrogen, water vapours and ammonia was circulated and subjected to electric discharge for several days.
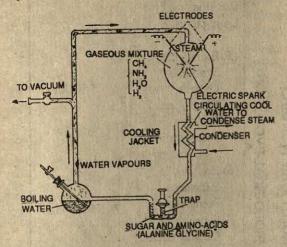
Fig. 39.5 Apparatus set up by Miller and Urey to demonstrate that simple organic compounds can be synthesized under conditions simulating the primitive atmosphere.

Since then, this abiotic synthesis of organic molecules has been repeated many times by a number of scientists and have recovered most amino acids present today in protein molecules and nitrogenous bases of nucleic acids.

Thus the essential building blocks of macromolecules (the amino acids and nucleotides) of living organisms could have been formed on the primitive earth.

The hot dilute soup–The synthesis of carbohydrates, fats, and amino acids and other complex organic substances probably occurred in sea which had been described by *HALDANE* as "The hot dilute soup", containing molecules of these organic substances in abundance.

Such organic molecules could not accumulate today because enormous number of micro-organisms use and degrade them as food and the oxygen present would destroy them and other intermediate products. But on the primitive earth, with the absence of oxygen and micro-organisms, such molecules could accumulate. According to thermodynamic rules such mole-

cules can not accumulate in solution in large numbers because they would break as fast as they were built up. Most probably, these organic molecules accumulated in layers on mud or clay, which also provided surface for continuous reactions.

Sources of Energy on Primitive Earth

The sources of energy available to these energy-requiring processes were :
  (i)   Ultraviolet radiation-from sun
  (ii) Ionizing radiation (protons, electrons and X-rays)
  (iii) Electric discharge (lightening)
  (iv) Heat - high temprature of earth.

2. BIOGENY
(From Molecules to Cells)

The next step in the origin of life was **polymerization** of these simple molecules leading to the formation of macromolecules or polymers the nucleic acids. Sydney Fox showed how upon heating amino acids get linked to form proteins macromolecules. Proteins are essential components of living beings both structurally and functionally. Nucleic acids were the first biochemical compounds capable of self duplication and marked the beginning of life by forming first gene. These represented a link between living and nonliving.

Formation of first Living being or First cell

The next problem was to explain how proteins and nucleic acids became organized to form first cell. According to FOX, the macromolecules formed spherical aggregates and occured as aqueous suspension. These were called **coacervates**. These grew by absorbing molecules from their environment. These also developed ability of replication and division, similar to bacteria and other simple unicellular or acellular organisms and most probably formed the first cell.

The first cells were preorganisms or **precells** containing self reproducing molecules (nucleic acids) enclosed in a lipid membrane. *OPARIN* called them **protobionts**. These were similar to Mycoplasma or virus. The precells most probably gave rise to **Monera** (cells without a well defined nucleus and

Protista (cells with a distinct nucleus). The Monera and Protista gave rise to Prokaryotes and also

Eukaryotes respectively. Monera developed into bacteria, Cyanobacteria etc. Protists gave rise to

```
C–Carbon
H–Hydrogen        }
N–Nitrogen

(1) CH₄–Methane
H₂O– Water        }  Ist Phase
NH₄–Ammonia
HCN– Hydrogen cyanide

(2) Amino acids
    Sugars (monosaccharides)
    Fatty acids         }  2nd Phase
    Purines
    Pyrimidines etc.

(3) Nucleotides
    Nucleic acids
    Proteins (enzymes)  }  3rd Phase
    Lipids and Fats
    Polysaccharides

(4) Nucleoproteins      }  4th Phase
    Coacervates-mutation
```

CHEMICAL EVOLUTION

BIOLOGICAL EVOLUTION

```
reproduction
nutrition          }
aggregation

(5) Early Cells
    Synthesis
    Growth
    Development     }  5th Phase
    Division
    Fermentation

(6) Early Cells
    Parasites
    Predators
    Saprophytes     }  6th Phase
    Chemosynthesis
    Photosynthesis

(7) Free Oxygen in
    atmosphere and  }  7th Phase
    aerobic respiration
```

Fig. 39.6 Summary of the seven phases of origin of life

YOUNG EARTH
DUST CLOUDS
HYDROGEN
AMMONIA
METHANE
PRIMITIVE ATMOSPHERE
COACERVATE DROPS
MICROSPHERES
FIRST ORGANIZED CELL
NUCLEIC ACID MOLECULE
SUN
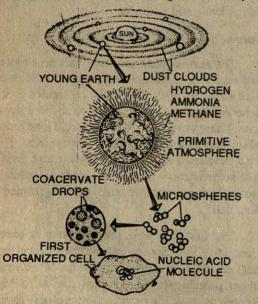
Fig. 39.7 Summary of origin of Life according to biochemi-cal origin of life

Eukaryotes that evolved into Protoza and Metaphyta.

3. COGNOGENY

(Evolution of mechanism of perception, expression and communication)

This involves diversification in Protozoa, Metaphyta and Metazoa. The evolution of first plants includes the advent of photosynthesis which appeared in both Monera and Protista due to exhaustion of available nutrient supply from the organic soup of sea, where life originated.

The Oxygen Revolution and Modern Atmosphere

With the increase of photosynthesizing organisms, Oxygen was liberated in the sea and then into the atmosphere. This free oxygen then reacted with methane and ammonia present in the primitive atmosphere and transformed them into CO_2 and free N_2.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
$$NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$$

These events ultimately transformed the ancient atmosphere with plenty of free oxygen. The modern atmosphere does not contain methane and ammonia but is mainly formed of water vapours, carbon dioxide and molecular nitrogen, hydrogen and large quantities of free molecular oxygen. Free oxygen finally lead to the evolution of aerobic mode of respiration which yielded more energy on oxidation of food stuffs compared to an aerobic respiration or fermentation (found in earlier forms).

WHERE LIFE ORIGINATED

Since many simpler and lower animals are acquatic and marine, and since the cells and body fluids of all animals contain salts, it is inferred that life began in the ocean. Many biologists believe that life originated in the tidal zone which is rich in oxygen, CO_2, light and minerals and is most suitable for plant and animal growth. The earliest animal remains are all in rocks of marine origin. Various organisms later invaded the freshwaters and land.
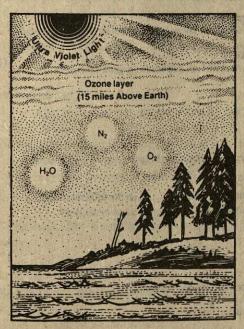
Fig. 39.8 Modern oxygenated atmosphere

FIRST ORGANISMS

It is presumed that the first living organisms were heterotrophs and presumably obtained energy by the fermentation of organic substances which were dissolved in the sea water, in which these organisms were residing. In course of time the sugar and amino acid molecules on which these first living forms were dependent gradually exhausted and CO_2 in the atmosphere became much more abundant. Presumably, it is at this time that the chlorophyll molecules arose and the heterotrophs evolved into autotrophs, which could manufacture their food from carbon dioxide and water. After the origin of autotrophic forms, the atmosphere got free oxygen that plants liberated during the process of photosynthesis. Thus the earlier forms differentiated into green and non-green cells, which have evolved into plant and animal kingdoms respectively.

LIFE ON OTHER PLANETS

Scientists presume the possibility of origin and presence of life on some other planets of universe, where conditions similar to those of the time when life originated on earth are still existing. The total number of stars in the universe is estimated to be 10^{23}. It is presumed that 5% of these stars may have conditions suitable for life. But most of the planets of solar system have temperature either too high or too low to support life and some of the planets do not have an atomsphere.

Moon lacks both water and atmosphere, therefore, there are no possibilities of the existence of life on moon. **Mercury** is extremely hot because of its nearness to the sun and it also lacks atmosphere. Therefore, it must also be barren and lifeless. Conditions on **Venus** are not properly understood, because its atmosphere is filled with dense white clouds, probably made up of something other than water vapours. The maximum knowledge about it so far suggests that it is extremely hot and dry. But **Jupiter, Saturn, Uranus** and **Neptune** have dense atmosphere made up of thick clouds of hydrogen, helium, methane and ammonia which are similar to primitive atmosphere of early earth. Therefore, it suggests all the possibilities of presence of life on these planets. But the planets are supposed to be too cold (temperature ranging from -2000 to -4000°F) that the water remains ever frozen. Since liquid water is very essen-

tial for life, the presence of life is improbable on these planets. Conditions on **Pluto** have not been explored out but most probably it is also very cold.

Mars is the only other planet where life could be supported. The temperature on its surface ranges from 30-60°C during day time. Its atmosphere is thin and composed of nitrogen, carbon dioxide and water vapours. Even scattered clouds have been observed in the atmosphere. Some astronomers have observed seasonal changes in the colour of Mars from bluish green to yellow or brown. Moreover, the photos sent by *Mariner-9* of America have shown the possibility of presence of life on Mars. But photos sent by Viking in 1976 have made the possibility of life on Mars doubtful.

There are possibilities of coexistence of life in the universe on many other celestial bodies outside the planets of our solar system. Among the billions of visible stars, there could be hundreds of other suns which have their own planetary systems and there could be millions of planets with conditions suitable to support life. This will be something very amazing to find life on planets other than earth.

QUESTIONS

1. Summarise Oparin concept of origin of life on earth.
2. What is modern concept of origin of life? Enumerate its essential features.
3. Describe briefly the contributions of Stanley Miller and Louis Pasteur.
4. Write what you know about the history of earth and origin of life.
5. Recall the experiment set up by Urey and Miller. What is the significance of their findings?
6. What are coacervates? Discuss their importance in the origin of life?
7. Mention difference between the primitive earth atmosphere and the present atmosphere of the earth. How the present atmosphere has evolved?
8. Enumerate the energy sources in the atmosphere of primitive earth which led to the synthesis of various organic molecules.
9. Describe Stanley Miller's experiment and explain how does it prove the biochemical theory of origin of life.
10. Explain with reasons:
    (i) The primitive atmosphere of earth was without oxygen.
    (ii) All organic compounds formed on the primitive earth had hydrogen and carbon.
    (iii) The sea on primitive earth was a broth of numerous organic compounds but it was not exposed to any disintegrating activities.
11. Describe two different methods of origin of first cell. How it looks like?
12. Enumerate the different steps in chemical evolution leading to the synthesis of self duplicating organic molecules.
13. Explain with reasons whether plants came first or the animals.
14. What is chemogeny?
15. Fill in the blanks-
    (i) The earth has originated 5.5 million years ago from ....
    (ii) The atmosphere of primitive earth was ....type.
    (iii) An atmosphere rich in hydrogen is a ....atmosphere.
    (iv) According to Oparin-Haldane theory of origin of life., the complex organic molecules on the primitive earth were formed in '................soup'.
    (v) The first photosynthetic organisms were ....
    (vi) The first cells must have arisin from aggregates of..............molecules, that formed ....in the aqueous medium.
16. What were the sources of energy on primitive earth, that are responsible for the formation of macromolecules?
17. Describe composition of atmosphere of primitive earth.
18. Answere the following :
(i) Where life originated?
(ii) What were the energy resources of primitive earth?
(iii) What came first animals or plants?
19. Describe the experiment conducted by Louis Pasteur to disapprove theory of abiogenesis.
20. How does Miller's experiment supports the theory of biochemical origin of life?
21. Give differences between the atmosphere of primitive earth and of the earth at present.
22. Give reasons :
(i) The atmosphere of primitive earth was of reducing type.
(ii) The compounds formed initially all had hydrogen.
(iii) The first living form was formed in the sea.

Interelationships among Living Organisms and Evidences

COMMON FEATURES OF LIFE PROCESSES

The earth is populated by enormous numbers of different kinds of living beings. These ranges from tiny microbes to giant sized trees, whales or elephants. According to theory of evolution, these have gradually evolved from more simple ancestral forms that existed in the past. Despite immense diversity of form and size, there is basic unity in the organization of all living beings, both in their basic structure and life processes.

A. Similarities in Structure

1. All living organisms are made up of one or more cells.
2. Diverse types of cells also have the same basic structure having same type of organelle.
3. All cells are made up of same types of macromolecule (proteins, nucleic acids, lipids and carbohydrates).

B. Similarities in Life Processes

1. All living organisms obtain matter and energy from their environment.
2. All living organisms utilise energy and matter to maintain life and to synthesize new cytoplasm.
3. All of them grow (increase in size) and reproduce (produce their own kind).

These basic functions involve two major life processes :

1. Energy transformation
2. Synthesis of key macromolecules - proteins and nucleic acids.

1. Energy transformation- The essential components of these two processes are identical or almost identical in all living organisms, ranging from bacteria to man, mouse, elephant or lion or giant trees or tiny plants. In all organisms glucose is metabolised to release energy for cellular function. The end product of glucose metabolism is same CO_2 and H_2O. The process involves the same basic steps in all and also all the steps of glucose metabolism are completed by same enzymes.

2. Synthesis of macromolecules (Genetic Code). Informations for the synthesis of various macromolecules of proteins is encoded in the sequence of nitrogenous bases in the DNA molecules (nucleic acid molecules). Presence of same *Codons* and *genetic code* in all living beings whether viruses, bacteria or man or mango, indicates that all living organisms have evolved from the same common ancestor.

Similarities in the mechanism of protein synthesis, use of similar type of tRNA, mRNA, enzymes and same amino acids during protein synthesis also support the same view.

3. Reproduction. All living organisms whether bacteria, algae, fungi, Amoeba, insects, fish or lizards produce offsprings of their own kind. These may reproduce asexually or sexually. Bacteria multiply asexually and very rapidly, say every few minutes. Some plants and animals reproduce only once in several years.

During reproduction, whether asexual or sexual, their genetic material replicates first and genetic informations are passed on from parents to the offsprings encoded in the DNA in the form of base-sequence. The same mechanism of DNA replication utilizing the same enzymes in all living beings indicates their common origin.

Such similarities among all living organisms suggest that all of them have evolved from a common early form of life.

EVIDENCES OF ORGANIC EVOLUTION

The convincing proofs or evidences in support of evolution are circumstantial and are drawn from the study of different branches of biology. These are :

1. Evidences from morphology, comparative anatomy and vestigial organs.
2. Evidences from embryology,
3. Evidences from palaeontology,
4. Evidences from taxonomy,
5. Evidences from geographical distribution of animals,
6. Evidences from biochemistry and comparative physiology,
7. Evidences from genetics.

1. Evidences from Morphology

A comparative study of various structures in different groups of vertebrates reveals a basic plan of organization indicating that animals have arisen from some common ancestral form by modification. Occurrence of homologous, analogous and vestigial organs in different animal groups provides evidences.

(i) **Homologous Organs**. These organs have a common origin and are built on the same basic pattern but perform different functions and are modified accordingly. Examine forelimbs of whale (flippers), bat (wings), bird (wings), horse, cat, frog and man. The forelimbs of whale are modified for swimming, of bat and bird for flight, of horse for running, of frog for leaping and forelimbs of man for grasping. Thus, the functions of forelimbs in these animals are entirely different and so also their external appearance. But these are constructed on the same pentadactyle pattern, consisting of almost the same bones (humerus, radioulna, carpals, metacarpals and phalanges), muscles, nerves and blood vessels arranged on the same pattern. The existance of homology in the structural plan of limbs of vertebrates can be explained only on the basis that all of them have evolved from common ancestors. Homology can be traced in the structure of skull and brain etc. Thus, homology in structural organization provides a convincing evidence for the concept of descent with modification.

(ii) **Analogous Organs**. These organs have almost similar appearance and perform the same function but they develop in totally different groups as totally different structures. Examine the wings of a butterfly, bird, bat and pterodactyle. These perform the same function of assisting in flight but differ
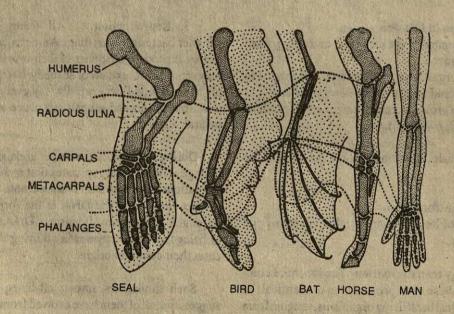
Fig. 40.1 Homology in the forearms of vertebrates.

considerably in their structure. The wings of an insect are mere
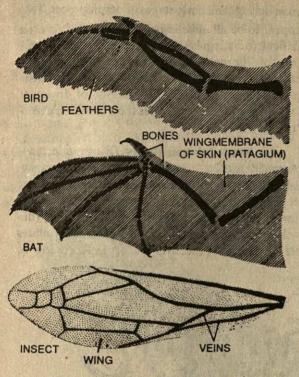
expansions of body wall without any skeletal support, the wings of pterodactyle and bat are skin folds supported by fingers and the wings of bird are modified forelimbs. This shows that these organs have developed the same functions in response to the same need but their basic architecture is different because these belong to animals having different ancestors.

(iii) **Vestigial organs** . Many structures in our body and in other animals and plants are nonfunctional and have practically no use but might have been large and functional in the ancestors. Such degenrate and nonfunctional organs are known as vestigial organs. As many as 90 such structures are present in our body. Presence of nictitating membrane, ear muscles to move pinna, pointed canines, wisdom tooth, vermiform appendix, mammae in male, caudal vertebrae (coccyx), abdominal muscles, hair coat on the body are only a few examples of vestigial organs in human body. The vestiges of pelvic girdles and

hindlimb bones in limbless pythons, vestigial wing bones and poorly developed sternum in flightless birds and vestigial eyes or eyes covered with fold of integument are other examples of vestigial organs.

It is presumed that vestigial organs were fully developed and functional in the ancestors but with the change in habit these were no more needed by the organisms and have gradually reduced to vestiges. As for example, the human appendix is the remnant of the caecum which is large and functional in all herbivorous animals. It helps in the digestion of
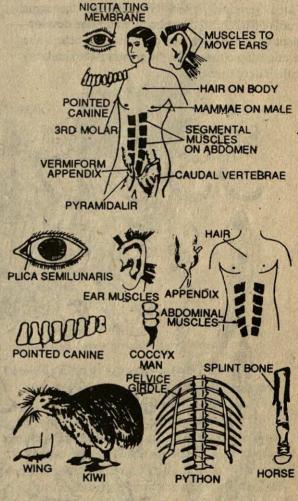
Fig. 40.3 Vestigial organs in Man

cellulose. The presence of nonfunctional appendix in man indicates that ancestors of man (primates) were herbivorous. Man being omnivorous does not require

Fig. 40.2 Analogous organs : A. Wing of Butterfly; B. of Pterodactyle; C. of Bird; and D. of Bat

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caecum or appendix. So these have undergone reduction in size.

The widespread occurrence of vestigial organs provides evidence for the occurrence of organic evolution.

2. Evidences from Embryology

(a) **Similarity in the early development of animals-** The early developmental stages of all the multicellular animals are similar. All start their life from a single cell called zygote. It develops into morula, blastula and gastrula. In gastrula the germinal layers i.e. *Ectoderm, Mesoderm* and *Endoderm* are formed. Three germinal layers give rise to the same types of parts in all the animals. Later, the development in different groups diverges. The nearer the relationship in the adults, the greater is the similarity in their development.

(b) **Similarity in Vertebrate embryos-** Study the embryos of fish, frogs, tortoise, pigeon, rabbit and man during their early stages of development. They appear to be all alike in appearance and it is even difficult to distinguish them. Moreover, the development of different organs (like kidney, heart, arteries etc) in all vertebtate embryos follows the same basic plan. This similarity in the embryos of divergent forms of vertebrates indicates their common ancestry.

(c) **Recapitulation theory** (Biogenetic law)- According to *ERNST HAECKEL* and *VON BAER'S* recapitulation theory, every organism during its development repeats in an abbreviated form the evolutionary history of its race. In *HAECKEL'S* words '**Ontogeny** (developmental history of an individual) **recapitulates its phylogeny** (ancestral history). Accordng to

FISHish SALAMANDER TORTOISE CHICK HOG CALF RABBIT MAN
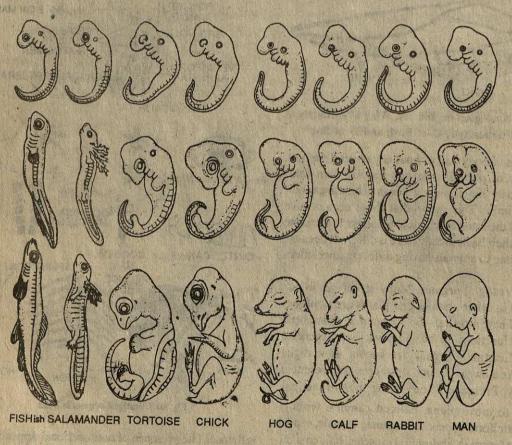
Fig. 40.4 Embryos from different vertebrates showing resemblance.

Haeckel the developmental stages of an organism resemble the adult stage of its ancestors, while according to *VON BAER* the developmental stages of an organism resemble the embroynic stages of its phylogenetic groups.

3. Evidences from Palaeontology

Palaeontology is the study of fossils of animals and plants of past geological ages. The traces, remains or impressions left by the organisms that lived in past, which have been presrved in rocks or otherwise, are called fossils. These offer a direct proof of evolution. Study of plant fossils is **palaeobotany** and animal fossils is **palaeozoology.**
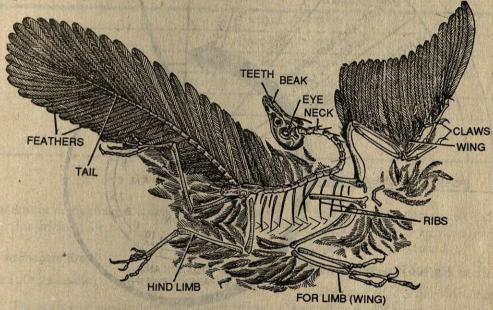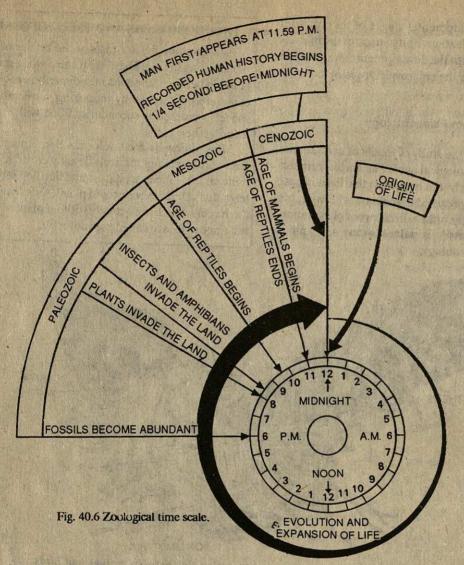
Fig. 40.5. Restoration of Archaeopteryx, a connecting link between reptiles and birds.

History of Life on Earth and Geological Time Scale

The history of evolution of life on earth is constructed by the study of fossil plants and animals from various strata of the earth. The most abundant fossils are formed by patrifaction in which hard parts like bones, teeth and exoskeleton of organisms are preserved in the rock strata. Their study can tell when and where the major groups of organisms arose, flourished, and either passed to extinction or evolved into new forms. In many cases it is possible to determine the environment in which those organisms lived.

Determination of Age of Rocks

To arrange fossils in chronological succession, it is necessary to determine their age. Scientists have found out radioactive disintegration method for this purpose. The radioactive substances like **Uranium, 238 Uranium, 235 Thorium, Radium, Potassium** and **Carbon14** etc. emit electrons from their outer rings and disintegrate into some stable non radioactive isotopes in a specific period. For example, one half of the total number of atoms of **uranium 238** change to lead 206 and helium in a period of 4.5 billion years. This period is known as half life of uranium. By accurately estimating the **uranium 238** and **lead 206** in

Fig. 40.6 Zoological time scale.

GEOLOGICAL TIME SCALE

a given rock, the age of rock can be calculated.

Radioactive Carbon method- Radioactive carbon (C^{14}) loses one-half of its radioactivity (i.e. C^{14}-C^{12}) in about 4760 years. When bones are formed small amounts of C^{14} are incorporated and its amount remains constant throughout the life of an organism. Upon death the radioactivity is gradually lost. By determining the amount of radioactivity in the bones, it is possible to approximate the time of death or fossilization. Since the half-life of C^{14} is small radioactive carbon dating method can give the age of fairly recent fossils (about 11,000 years to recent).

By studying types of fossils in different rock strata and determinig their age by radio-active dating method, geologists have constructed a geological time scale or stratographical scale. This scale is the calendar of earth's past history indicating the evolution of life through time recorded in the sequence of rocks. The geological time has been divided into six eras which are divided into periods and periods into epochs each one being characterised by some specific living forms, specific geological disturbances and climatic changes.

1. Azoic Era (Era without life)

During this period earth was formed, cooled and

AZOIC	ARCHAEOZOIC	PROTEROZOIC	PALAEOZOIC						MESOZOIC			COENOZOIC									ERA
		PRECAMBRIAN	CAMBRIAN	ORDOVICIAN	SILURIAN	DEVONIAN	CARBONIFEROUS	PERMIAN	TRIASSIC	JURASSIC	CRETACEOUS	TERTIARY						QUATERNARY			PERIOD EPOCH
												PALAEOCENE	EOCENE	OLIGOCENE	MIOCENE	PLIOCENE		PLEISTOCENE	RECENT		

INVERTEBRATES
FISHES
AMPHIBIANS
REPTILES
BIRDS
MAMMALS — MAN

ALGAE, BACTERIA
LIVERWORTS (BRYOPHYTA)
PSILOPSIDA AND LYCOPSIDA (CLUB MOSSES)
SPHENOPSIDA (HORSE-TAILS) AND PTEROPSIDA (FERNS)
GYMNOSPERMS
ANGIOSPERMS

ANIMALS / PLANTS

Fig. 40.6B Summary of Eras of Geological History of Earth.

underwent many changes creating conditions suitable for origin of life.

2. Archeozic Era

(Era of ancient life)

This era is presumed to have started much before 2,000 million years ago. Bacteria-like and alga-like fossil materials have been found in South Africa These indicate that simple unicellular organisms **Protophyta** (unicellular plants and animals) were present during this era.

3. Proterozoic Era (Era of primitive life) or Precambrian Period

The era is supposed to have started about 2,000 million years ago and was spread out for 1,500 million years. The fossil records are meagre because the living forms were soft bodied. Fossils of bacteria, bluegreen algae, algae and fungi in plants and sponges, (shelled protozoans) radiolarians, jelly fishes, corals, round worms and brachiopods in animal groups have been found.

4. Palaeozoic Era (Cradle of ancient life)

The era started about 600 million years ago and had a duration of about 370 million years. Its fossil records are extensive and represent ancestors of almost all the phyla of plants and animals living today. The era is divided into 6 periods- **Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian. Land plants appeared in** Cambrian period and deversified in Devonian. Club mosses, ferns and gymnosperms formed thick jungles on swampy land during Carboniferous. These have given rise to the major coal deposits of the world.

The dominant groups of ferns were tree-like **calamites and pteridosperms** (the connecting link between ferns and pteridophytes).

All the major invertebrate phyla were represented in Palaeozoic era, but trilobites (the distant

relatives of present day lobsters) were most abundant. The first vertebrates appeared as armoured, jawless and finless fishes, the **ostracoderms**. The first air-breathing animals that appeared during mid Palaeozoic era were scorpion-like arachnids and wingless insects. Amphibians were represented by stegocephalians and the first reptiles diverged from amphibians.

Triassic (early Mesozoic), marsupials in Jurassic (Mid Mesozoic) and archaic eutherians in Cretaceous. The first birds appeared in Jurassic period. The fossils of two birds- Archaeopteryse and Archaeornis have been obtained from this era. In plants Gymnosperms were dominant with widely spread out cycades and conifers. The first Angiosperms also appeared in Jurassic period.

Fig. 40.7 Reconstruction of a trilobite.

Fig. 40.8 Some of the dinosaurs-
(A) Tyranosaurus   (B) Brontosaurus
(C) Struthiominus   (D) Triceratops

In Grand Canyon in Arizona, the eroding action of Colorado River has exposed a series of strata in a two kilometres deep cut. It illustrates fossil records from some 500 million years onward, arranged in chronological sequence.

5. Mesozoic Era (Era of Intermediate Life)

This era began about 230 million years ago and ended about 63 million years ago. It is divided into three periods : **Triassic, Jurassic** and **Cretaceous**. This is commonly known as 'Age of reptiles', because reptiles evolved, diversified and became the rulers of the earth. They occupied land (**Dinosaurs**), sea (**Ichthyosaurs and Pleisosaurs**) and air (**Pterosaurs**). The dinosaurs which means the terrible lizards, acquired extraordinary size and were the biggest animals that ever walked on land. Some of them are *Tyronosaurus* (50'), *Brontosaurus, Ankylosaurus, Branchosaurus, Triceratops*. These finally became extinct by the end of Mesozoic era in Cretaceous Period. The first egg laying mammals evolved during

Fossil records have also been studied in India. These have been exposed in Kashmir Valley, Madhya Pradesh, Bihar and Orissa. These were discovered and studied by Palaeobotanists of Birbal Sahani Institute, Lucknow. The fossil deposits span a gap of 3500 million years. The important **national fossil parks** in India are :

1. Fossil forests preserved in interterappean sediments between streaming lava in Deccan country.
2. Fossil forest about one hundred million years old are obtained in Rajmahal Hills in Bihar.
3. About 260 million years old coal forests have been discovered from Orissa.

6. Coenozoic Era (Era of Modern Life)

Coenozoic era is popularly knows as 'age of mammals'. It is most recent, has an estimated duration of about 63 million years and is still continuing. This era is characterised by great adaptive radiation in birds, insects and mammals. There was gradual replacement of jungles by grasslands. Monocot and herbaceous plants appeared.

(i) Distribution of fossils in the rocks. The distribution pattern of fossils shows that ancient fossils present in the bottom rocks are simple, while the most recent fossils found in the upper strata are more highly evolved. It means fossil forms become more and more complex as we proceed from earliest to the recent rocks. The fossils of man, the most highly evolved animal, are found only in the recent rocks.

(ii) Missing links. A few fossils are found to be intermediate in their structure exhibiting features of two groups of living animals, e.g. *Archaeopteryx*, a fossil bird has retained certain reptilian features. Thus it is a 'missing link between reptiles and birds' and suggests that birds have evolved from reptiles. The fossil **Pteridosperms** that existed in Corboniferous and Permian periods, form a connecting link between ferns and gymnosperms. Their leaves resemble those of ferns but the stem showed secondary growth and seeds like gymnosperms.

(iii) Evolutionary history of individual forms. The palaeontologist, by the study of fossils, have traced out the complete evolutionary history of some animals such as **horse, elephant, camel** and **man.**

The fossil records show that the ancestors of horse were small-sized, fox-like forms (A) present in Eocene period of Coenozoic era. These had four toes in fore-foot and three toes in the hind-foot. These gradually lost some of their toes. They also grew in size and acquired modifications to suit grass-land life of fast running. Thus the present-day, large sized horse, *Equus* (Fig. 4.17) having a single functional toe and two splint bones in each foot, has been evolved.

From the evolutionary history of horse we can say, with full justification, that other animals have also evolved in the same manner.
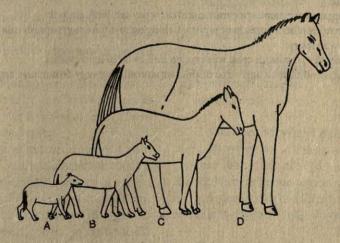
Fig. 40.9 Evolution of Horse

| A. *Eohippus* (in Eocene) | B. *Mesohippus* (ni Miocene) | C. *Merychippus* (in Pliocene) | D. *Equus* (in Pleistocene and recent era) |

EXERCISES

1. Give differences between analogy and homology.
2. Why flippers of seal, wings of bat and forelimbs of horse and man are homologous organs ?
3. How vestigial organs provide evidence in support of organic evolution ?

4. Why Archaeopteryx is called a connecting link between reptiles and birds ?
5. Explain in brief the recapitulation theory.
6. Discuss significance of fossils.
7. Name five vestigial organs found in man.
8. What do you mean by organic evolution ? Discuss evidence in favour of organic evolution from comparative morphology.
9. Write short notes on :
   (i)   Appendix vermiform   (ii) Homologous organs
   (iii)   Vestigial organs   (iv) Fossils.
10. Justfy the statement, 'Fossils provide the written story of organic evolution.'
11. What is recapitulation theory ? How it proves the theory of organic evolution ?
12. Explain the following :
    (i)   Palaeontology   (ii) Fossils
    (iii)   Geological time scale   (iv) Mass extinctions
    (v)   Pseudomorphs   (vi) Connecting links
13. Explain which of the following are homologous and which are analogous and why ?
    (i) Fish scales and cuticular exoskeleton in Arthropods.
    (ii) Wings of a bird and a bat.
    (iii) Nails and claws in mammals.
    (iv) Nails in mammals and claws of scorpion.
    (v) Ginger and sweet potato.
    (vi) Trunk of an elephant and hand of a chimpanzee.
14. How the age of fossils can be determined ?
15. Name basic characterstics of life common to all organisms.
16. Enlist vestigial organs found in man.
17. Make true or false :
    (i) Homologous organs have same appearance and carry out similar functions.
    (ii) A comparative study of structures in organisms belonging to different groups reveals similarities which point towards common ancestry.
    (iii) Million of years ago, the earth crust was broken into isolated land masses.
    (iv) Microbes, plants and animals appear so distinct structurally that they do not have anything in common biologically.

□ □

Theories of Evolution

Various theories have been postulated by different scientists, Lamarck's theory and Darwin's theory are of special significance.

1. LAMARCKISM

Inheritence of Acquired characters

LAMARCK theory of evolution was published in 'Philosophie Zoologique' in the year 1809. It is popularly known as **'The Inheritance of Acquired Characters in Organisms'** and comprises of four propositions or assumptions :

1. Living organisms and their parts tend to increase in size continuously due to internal forces of life (Origin of need).

2. Formation of a new organ in the body of organisms is the result of a new need and new movement which this need initiates and maintains in the body **(Effect of need).**

3. If an organ is used continuously and constantly, it will tend to become highly developed, whereas disuse results in its degeneration(**Use and disuse).**

4. Modifications acquired during the life time of an individual are inherited by its offspring. It means changes are cumulative over a period of time (**Inheritance of Acquired characters).**

Lamarck's theory was exposed to severe criticism. AUGUST WEISMANN in late nineteenth century, had conducted several experiments with mice tail and had shown that mice tail regenerated even when it was cut off generation after generation. He argued if Lamarck's theory is correct, the tail in mice should have been reduced.

2. DARWINISM

(Origin of Species by Natural Selection or Theory of Natural Selection)

DARWINISM is the term coined for the explanation offered by DARWIN for the origin of species by Natural Selection. Darwinism does not exactly mean what evolution is, but it explains how evolution might have occurred in nature. This explanation has been beautifully elaborated by DARWIN in his book entiled **"The origin of Species by Natural Selection"**. Although Darwin's chief ideas have been anticipated by his predecessors, his convincing representation has been appreciated the world over both by scientists and laymen. Darwinism or theory of Natural Selection is based on three observable facts of nature from which deductions have been made in the form of a theory. The facts and deductions can be summarised as under :-

Facts	Deductions
(i) Individuals multiply in geometric ratio	**1. Struggle for existance**
(ii) Number of survivors remains roughly constant	
(i) Struggle for existance	**2. Survival of the fittest and natural selection**
(ii) Variations and heredity	
(i) Survival of the fittest	**3. Origin of a new species**
(ii) Continued changes (adaptations)	

1. Over production - Organisms produce many more offsprings than can possibly survive. Plants produce thousands of seeds, salmon fish produces 28,000,000 eggs in one season and a rabbit produces about 6 young ones in a litter and four litters per year and insects lay hundreds of eggs per season.

2. Struggle for existence - According to Darwin individuals multiply in geometric ratio whereas space and food available remains constant, so there is an intense competition and three fold struggle for existence. The struggle is **intraspecific, interspecific and struggle with the environment.**

3. Variations and heredity. The offsprings are similar to their parent and also exhibit some resemblance to each other. But they are not identical. They differ to some extent in shape, size, colour and

behaviour etc. It means that individuals in a population always show some variability for almost every character.

4. Natural Selection and Survival of the Fittest- During struggle for existence, only some off-springs are able to survive and reach adulthood. Those who become adult reproduce offsprings similar to them. This is called **reproduction**. Since all offsprings, produced during reproduction do not survive. It means number of offsprings contributed to the population by each individual varies. This is called *differntial reproduction*.

Charles Darwin had emphasized that (i) all living organisms have a common origin and (ii) Species of organisms are not static. These accumulate many small changes. These variations get accumulated over many generations and finally lead to the origin of a new species.

SOURCES OF VARIABILITY

All individuals of a species have same number and same type of chromosomes and genes therein, but still they differ in their morphology, physiology and behaviour. These differences may be heritable or nonheritable and are classified as **somatic** and **germinal.**

1. Somatic or somatogenic and germinal or blastogenic variations- The somatic variations are caused by the direct influence of the environment upon the body of the organisms. These are local changes in the organisation and are neither inherited from parentis nor transmitted to the offsprings. These are lost with parents death. These are also described as **acquired variations.**

LAMARCK in his theory of inheritance of acquired characters laid emphasis on the transmission of these acquired variations from one generation to other.

2.The germinal or blastogenic variations occur in the germplasm of the organisms. The germ cells or gametes develop from the germplasms and on fusion form the zygote which develops into the adult. Therefore, the variations from the germplasm and the gametes are passed on to the offsprings.

Causes of Variations- Somatogenic variations are caused by changes in atmospheres. These variations are produced due to different expressions of the identical genes under different circumstances. Germinal variations are due to change in the genes. These introduce genotypiee differences in the individuals of a population. Genotype variations are not only important but essential for the evolution.
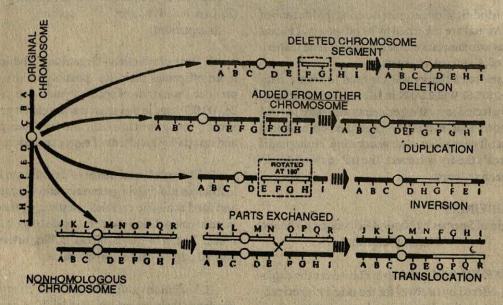
Fig. 41.1 A diagramatic Representation of Chromosomal abbreations

Genetic variations in populations are introduced in the following ways :

I. Origin of New Mutations

1. **Gene Mutations**
2. **Chromosomal Mutations or Chromosomal Aberrations**

    (a) Changes in number of genes

(i) *Deletion* or *deficiency*- loss of one or more genes

(ii) *Duplication*- addition of one or more genes

    (b) Changes in the arrangement of genes

(i) *Inversion*- rotation of a block of genes in a chromosome at 180°.

(ii) *Translocation*- exchange of parts between non-homologous chromosomes.

3. *Change in the Number of Chromosomes (Heteroploidy)*

    (a) Changes involving entire sets

(i) *Haploidy*- having only one set of chromosomes i.e.,n-chromosomes

(ii) *Polyploidy*- each set of chromosomes is represented more than twice.

    Triploidy-3n

    Tetraploidy-4n

    Pentaploidy-5n

    (b) Changes involving the number of chromosomes in one set of chromosomes.

(i) *Monosomic*: loss of one chromosome from one set : 2n-1

(ii) *Polysomic*- addition of one or more chromosomes to one set : 2n + 1 or 2n + 2

(iii) *Nullisomic*-loss of both the chromosomes of a pair : 2n-2.

II. NEW COMBINATION OF OLD GENES OR RECOMBINATION

1. Mendelian recombination and random assortment of genetic meterial.
2. Crossing or exchange of genes between chromosomes.
3. Introgressive hybridization.

A. Causes of Genetic variations At Individual level

1. **Gene Mutations**

    Gene mutations are the basic source of variability. These are changes in the number or sequence of nucleotides or nitrogenous bases in DNA molecule

forming a gene. These are caused either by addition of one or more nucleotides in a DNA molecule or their loss or by the substitution of some nitrogenous bases by others. As a result of gene mutations, the phenotypic expression of a particular normal gene alters. For example, gene for sickle cell anemia is a mutant of the normal gene and is responsible to synthesize abnormal haemoglobin with less oxygen carrying capacity.

2. **Recombinations**- Because of sexual mode of reproduction, the genes from two different parents (male and female) come together. As a result, new combinations of their genes are formed and are passed on to their offsprings. At the time of gamete formation (i.e. during meiosis), crossing over and exchange of chromosome segments also result in new combinations of dominant and recessive genes.

B. Genetic variations At Population Level

At population level, the genetic variations are introduced by chromosomal mutations. These include changes in the number of genes in the chromosome (Deletion and duplication) or changes in the arrangement of genes in the chromosomes (transition and transversion).

Another method of genetic variability is introgressive hybridization between individuals of two different species. Change in the chromosome number (**polyploidy and aneuploidy**) also introduce genetic variability and help in the origin of new species.

Significance of Genetic Variability (Adaptation and Survival)

The success in survival and reproduction depends on the characterstics of the individuals. Certain characters or combination of certain characters (i.e. certain genotypes) may prove to be more successfully adapted than other genotypes. For example, a rice variety from central India *Oryza nivara* was found to be resistant to grassy stunt virus infection and survived whereas other varieties of rice crop were all destroyed due to infection in early 1930s. Similarly, during severe draught, plants and animals which can efficiently minimize the lose of water and maximize water absorption have better chances of survival. It means adaptations play a major role in survival. In the

struggle for existence, only those organisms manage to survive that are well adapted to the environment. In other words natural selection selects and favours the multiplication of those genetic variations which are of adaptive value to the organism or to the population by encouraging survival and reproduction of individuals with such gene combinations.

Natural Selection

Natural selection favours those features of the organisms of a population that bring them into more efficient adaptive relationship with their abiotic and biotic environment. If qualities that enable an organism to survive and reproduce, are heritable, the offsprings of such parents with these qualities will also be fit and successful. Gradually, the number of such individuals in a population increases. It shows that natural selection has favoured those qualities and the individuals carrying those qualities.
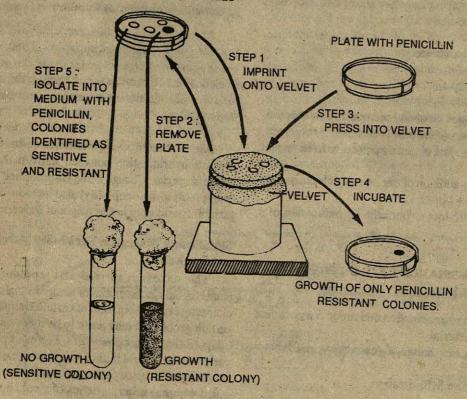
If there are no variations in the individuals of a population, there will be no adaptive modifications and no selection and then no evolution.

Lederberg Replica Plating Experiment To illustrate Selections -

JOSHUA LEDERBERG and ESTHER LEDERBERG conducted experiment on bacteria to demonstrate genetic basis of a particular adaptation. They obtained a 'master plate' of bacterial culture by inoculating dilute suspension of bacteria on an agar plate. After a period of growth the master plate contained

PLATE WITHOUT PENICILLIN
HAS BACTERIAL COLONIES

STEP 5 :
ISOLATE INTO
MEDIUM WITH
PENICILLIN,
COLONIES
IDENTIFIED AS
SENSITIVE
AND RESISTANT

STEP 1
IMPRINT
ONTO VELVET

PLATE WITH PENICILLIN

STEP 2 :
REMOVE
PLATE

STEP 3 :
PRESS INTO VELVET

STEP 4
INCUBATE

VELVET

GROWTH OF ONLY PENICILLIN
RESISTANT COLONIES.

NO GROWTH.
(SENSITIVE COLONY)

GROWTH
(RESISTANT COLONY)

MEDIUM WITH
PENICILLIN

Fig. 41.2 Lederberg's replica plating experiment

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severel bacterial colonies. Each colony of bacteria represented a clone being originated from a single bacterial cell as a result of repeated mitotic divisions. Replicas of the master plate were prepared on new agar plates.

Next, they tried to grow bacteria on replica plates with an antibiotic such as penicillin. Most colonies of the master plate failed to grow on replica plates with antibiotic. The few colonies that could be formed were resistant to penicillin. It means that certain bacteria have acquired the ability to survive and multiply in a new environment. This mutant strain of bacteria has developed an adaptation.

There can be two possible explanation for this adaptation-

1. According to **Lamarckian view**, penicillin somehow induced a change in some bacterial cell, enabling them to grow in penicillin containing medium.

2. According to **Darwinian interpretation**, the original suspension of bacterial cells, contained few mutant bacteria which contained mutant genes enabling them to survive the effect of penicillin and form colonies.

Lederberg's experiment illustrates two basic points-

1. **Survival value of the penicillin resistant character**
2. **Role of natural selection in fixing this character in the bacterial colony.**

It shows that certain bacterial cells in the original bacterial suspension or in the original master plate were **penicillin-resistant mutants**. But these were very few in number. This mutation has arisen by chance. These mutants had no clear advantage in a penicillin free environment. Therefore, in penicillin free environment, this mutant gene or mutant character had no survival or adaptive value and was not being favoured by natural selection. In penicillin-containing agar plates the penicillin resistant mutants had a clear-cut selective advantage on penicillin-sensitive bacteria. Therefore, selection or Darwin's natural selection has favoured this genotype against penicillin-sensitive bacteria and leading to an increase in the number of bacterial cells containing mutant penicillin-resistant character.

QUESTIONS

1. Explain briefly 'Darwin's Theory of natural selection'
2. Give salient features of Lamarcks theory of evolution.
3. Explain 'struggle for existence'.
4. What are the causes of germinal variations ? Discuss their role in origin of species.
5. Explain Lederberg's plating experiment.
6. Discuss the significance of Lederberg's plating experiment.
7. Discuss significance of genetic variability in evolution.
8. Differentiate between:
    (i) Darwinism and Lamarckism.
    (ii) Recombination and hybridization.
    (iii) Natural selection and artificial selection.
    (iv) Germplasm and somatoplasm.
    (v) Somatic and Germinal variations.
9. Explain the results of Lederbergs plating experiment in the light of Lamarckism and Darwinism.
10. Discuss role of variations in evolution.
11. Complete the following :
    (i) Modifications acquired during life time of an individual are inherited by its offsprings. This rep resents theory of -
    (ii) Over production in plants and animals leads to - - - - - - - - - - - - - - - - - - -
    (iii) Natural selection is differential - - - - - - - of the organisms.
    (iv) Heritable variations are -

prey, predators and competing organisms of other species) or both. Genetic divergence in populations of a species increases by the accumulation of genetic differences introduced by mutations, recombinations and hybridization.

Mutations occur at random. In different populations different mutations accumulate by chance alone irrespective of whether the two environments are similar or not. By the action of natural selection the mutations of survival value are fixed in the gene pool of the populations, making them more adapted to the environment. In absence of gene flow between any two isolated populations of a species, in due course of time, the number of such mutations reaches a point at which the two populations become so different that they are no longer able to interbreed. Thus with the establishment of *reproductive isolation* the two populations become two distinct species.

Example: Darwins finches present on Galapagos. Islands, some 600 miles off the coast of Ecuador provide an example how isolation can help in speciation. At present there are 13 species of finches specialized to feed on cacti, seeds and insects. Some insectivorus finches have evolved behavioural features common to woodpeckers like long pointed beak and clinging feet. None of them resembles to the parental seed eating finches of South American mainland.

Most probably, a few seed eating finches or perhaps a single previously mated female had reached Galapagos islands from mainland in distant past. In absence of competition, the population of finches diversified and became adapted to different habitats or ecological niches and evolved into new species. Thus geographical isolation has led to the development of reproductive isolation and thereby to the origin of new species. This type of speciation is called **allopatric speciation** (evolution of species occupying different geographical areas).

Polyploidy (i.e. multiplication of the chromosome sets) leads to the formation of new species more rapidly. Organisms having chromosomes in the multiples of basic set are called polyploids.

T. monococcum
2n = 14
AA

T. searsii
(a close relative
of the suspected
B genome donor)
2n = 14
BB

T. turgidum
4n = 28
AABB

T. tauschii
2n = 14
DD

T. aestivum
6n = 42
AABBDD
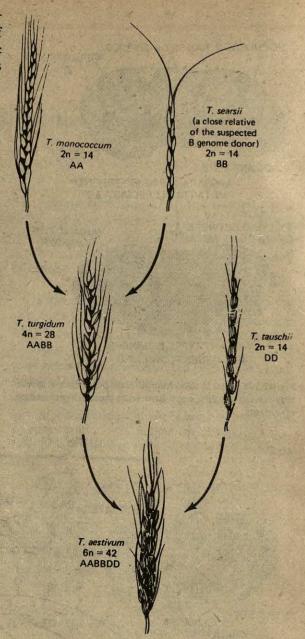
Fig. 42.6 Origin of species in wheat by polyploidy

These may be
1. Triploids–3n
2. Tetraploids–4n
3. Pentaploids–5n
4. Hexaploids–6n
5. Octoploids–8n etc.

Polyploidy establishes reproductive isolation among individuals of the same population occupying same area. This type of speciation is called **sympatric speciation**. About one third of all plant species are polyploids. Different species of wheat have arisen by polyploidy.

Types of Isolating Mechanism
(PREMATING MECHANISMS)

BARRIERS

EXTERNAL

I. *Isolating mechanisms which prevent interspecific crosses*

A. **Potential mates do not meet**
 1. Geographic isolation
 2. Isolation due to distances ⎫ Ecological
 3. Climatic isolation ⎬ isolation
 4. Seasonal isolation ⎪
 5. Habitat isolation ⎭

B. **Potential mates meet but do not mate**
 6. Ethological isolation

C. **Copulation attempted but transference of sperms does not occur**
 7. Mechanical isolation
 8. Physiological isolation

(POSTMATING MECHANISMS) *Isolating mechanisms which reduce full success of interspecific crosses*

INTERNAL BARRIERS

A. **Sperms are transferred but eggs are not fertilized**
 1. Gametic mortality
B. **Egg is fertilized but zygote is unviable**
 2. Zygote mortality
C. **Zygote produces F$_1$ hybrid of reduced viability**
 3. Hybrid inviability
D. **Hybrid is viable but partially or completely sterile**
 4. Hybrid sterility. mules and henny - hybrids of donkey and horse.

Role of Natural selection and Genetic Drift in Speciation

A. Natural Selection

Natural selection is described as a guiding force of evolution. It is the *differential and non random reproduction* of divergent genotypes in a population.

1. Differential reproduction- Natural selection brings about evolutionary changes by favouring differential reproduction of genes or gene combinations. Differntial reproduction of genes produces changes in the gene frequency from one generation to next.

The differential reproduction is achieved either by the increased rate of reproduction or by the decreased vulnerability to environmental agents responsible for mortality.

2. Encouragement of beneficial genes. Selection is further characterised by encouragement of genes that assure highest level of adaptive effeciency between the population and its environment. It means when two or more gene combinations are present, selection favours increased reproduction of the gene combination which is most suitable under the environmental conditions. Therefore, natural selection brings about improved adaptive relations between organisms and environment by favouring the reproduction and survival of those individuals which are found more suited to the environment.

How natural selection favours the reproduction of particular genotype and forces change in the gene equilibrium can be illustrated by the following example :

In a population of *Drosophila melanogaster*, all the females (whether white-eyed or red-eyed) prefer to mate with the wild-eyed (red) males, but if white-eyed males are the only mates available, they are compelled to mate with them. It means that white-eyed gene is eliminated from the population as a result of selection, which acts through mating preference. Moreover, selection produces and adaptive improvement, because wild-eyed males have better environmental relation. Natural selection is, there-

fore, a creative force in evolution as it favours eficient gene combinations.

B. Random Genetic Drift or Sewall Wright Effect

In large populations gene frequency either remains constant or exhibits a directional change. But in small populations because of sampling errors, the gene frequencies exhibit great fluctuations generation after generation. In one generation these may increase far beyond the normal range and may decrease extremely in the next. These deviations are nondirectional. These are described as chance events. SEWALL WRIGHT (1931) applied the term **random genetic drift** to this type of change. Some geneticists call it the **'Sewall Wright Effect'** *or the* **scattering of variability.**

Effect of genetic drifts. Genetic drifts have two principal effects on populations of small size:

1. Fixation of new mutations. Genetic drifts fix new alleles of genes that arise by mutation from time to time.

2. Reduced variability. Genetic drifts reduce genetic variability in the populations by eliminating one of the two alleles either new or the old. Thus eliminating effect of genetic drifts is called decay of variability.

Examples of Natural Selection

1. Industrial Melanism:

The industrial melanism in the peppered moth, *Biston betularia*, provides a well-studied example of directional natural selection. In the early part of nineteenth century there was a dramatic rise of industrialization in Europe. The black sooty smoke fell upon the countryside and covered forests and fields with various amounts of soot. This changed the usual colour of the trunks from mottled greenish grey to black.

The wing colour of the typical peppered moth was mottled gray that blended perfectly with lichen-covered tree trunks, and protected it from the enemies. Until 1845 only light coloured moths were known in England. In 1845 the first dark coloured peppered moth was seen in the region east of Manch-

ester. This variant was named *Biston betularia carbonaria*. During next 50 years the frequency of dark individuals gradually increased from less than 1 to about 99% in the vicinity of industrial areas. Today only a few light coloured moths persist.

The reason for this striking increase in the number of melanic variety was worked out by E.B. FORD and H.B.D. KETTLEWELL. FORD found that the caterpillars of melanic variety (carbonaria) were more vigorus and viable, capable to withstand the environmental hardships much better than the wild type.

KETTLEWELL showed and proved that, though having greater survival value, the melanic variety could not survive in the nonsooty forest, because the birds could locate them on lichens. So these were being devoured by birds irrespective of their number. With the elimination of lichens the carbonarias were cryptically coloured and the wild type were not, Therefore, the melanic variety became abundantly distributed in due course of time (Fig. 42.7).

Here the environmental factor that has selected the melanic variety against the wild type is the bird predation. The natural selection has operated in the direction of eliminating gene for light colour and gradual increase of gene for dark pigment. The mutant for melanism is dominant.

2. Resistance of Mosquitoes to Pesticides

When DDT was introduced to control mosquitoes, it proved to be a successful insecticide. But now it has become ineffective against mosquitoes. It can be explained that—

The original population of mosquitoes had some DDT-resistant individuals. In absence of DDT such DDT-resistant individuals had no additional adaptability or survival value over DDT sensitive mosquitoes. Natural selection favoured them only when DDT was sprayed on large scale. Therefore DDT resistant genotype became more and more numerous. Over a period of time the entire population became DDT-resistant type.

3. Sickle Cell Anaemia

Sickle cell anemia is a disease of human beings, found specially in Negroes. The R.B.Cs. in this

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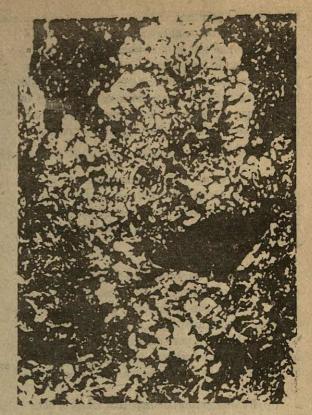
Fig. 42.7. Effect of industrial melanism as a factor of natural selection

disease become sickle-shaped in venous blood owing to the lower concentration of oxygen. This causes rupture of cells and severe haemolytic anaemia. Individuals homozygous for abnormal haemoglobin die at an early age. In heterozygotes, the RBCs containing abnormal haemoglobin become sickle-shaped and unable to bind oxygen.

Why this character has not been eliminated from human population by natural selection ? The detailed studies have shown that malarial parasite that live in RBCs are unable to grow in sickle-shaped RBCs. It means individuals heterozygous for sickle celled gene are able to cope with malarial infection whereas the normal person with normal RBCs suffer from severe malarial infection.

This shows that natural selection favoured the sickle celled character and thereby the gene controlling it, because it has survival value in malaria infested rigions. For this reason, Character is found in Negroes living in malaria infested belt in the world.

MIMICRY

The English naturalist HENRY W. BATES in 1862 propunded the theory of mimicry based on the study of butterflies frm the forests of Brazil, Which means to imitate closely or to simulate.

"Mimicry is the superficial but close resemblance of one organism to another or to natural objects among which it lives, that secures it concealment, protection or some other advantage" so that it either escapes itself from observation or advertises as being harmful, which is not actually the case.

The organism which mimics is known as mimic or mimetic and the organism or object which is imitated or copied is called the model. The mimetic imitates other organism not only in shape, size and colour but in action and attitute also.

KINDS OF MIMICRY

Mimicry can be classified into three categories:
1. Protective Mimicry
2. Aggresive Mimicry
3. Conscious Mimicry

1. Protective Mimicry

The *protective mimicry* includes those cases in which the organisms mimic either some organism or natural object in form, colour or behaviour and thus protect themselves from their predators. This could be obtained either by *concealment* or by *warning*. In concealing type of protective mimicry is very common amongst animals. The organisms conceal or camouflage them.

(i) *By altering their colouration to fit the background*. The pupae of the swallow tail butterfly, Papilio machaon, look green when attached to plane stems and grey when attached to the free trunks or stones.

(ii) *Search a background which matches their colour*. The caterpillar of Noctuid moth 'Hyloicuspinastri' is blue green in colour in juvenile stage and bears six longitudinal white stripes. It rests on pine needles, where it is very difficult to pick it out. But after last moult it rests on the brown twigs and is brown in colour with irregular white and black flecks.

(iii) *By Mimicrying the shape and colour of other organism or object.*

Indian dead leaf butterfly, *Kallima paralecta*, is a classical example of protective mimicry. Its wings are brilliantly coloured above but have dull brown undersurface which resembles a dry leaf.

2. Warning mimicry

The nonpoisonous and harmless organisms mimic the poisonous and harmful organisms and the palatable forms resemble and and advertise to be nonpalatable. This type of mimicry is helpful in self defence.

Certain non-poisonous coral snakes of family *colubride* exhibit colour pattern of poisonous coral snakes belonging to the family *Elapidae*. These have alternating bands of bright red and black colour edged with yellow.

B. Alluring mimicry - In this type of mimicry the animal possesses some lure to attract its prey, whereas it blends itself with the sorrounding. The misleaded animals fall victim and form the prey of mimic.

(i) Certain spiders mimic the flowers of orchid and the insects lured to collect honey are devoured.

Kallima, the INDIAN DEAD-LEAF BUTTERFLY

Fig. 42.8 Showing Protective Mimicry

(ii) Angler fish, *Lophius*, lives at the sea-bottom and camouflages with it. The first fin ray of dorsal fin is located on dorsal edge of upper lip some distance in front of eye. This ray is known as illicium. It can rotate freely in its ball and socket joint and bears a fleshy cutaneous appendage the bait at its free end. The bait is held in front of mouth and swings in all directions. If another fish snaps at this dummy prey, the angler fish swallows it immediately.

(iii) The American horn frog - *Ceratophrys*, sits still and moves one finger of the hand. This arouses the attention of other animals including small frogs. When other animals attempt to capture the apparent prey, are preyed upon by *Ceratophrys*.

(iv) Spiders Lasso and Bolo do not web. Instead they produce a single horizontal thread from which they suspend themselves. Another thread with a terminal sticky droplet acts as trap-thread. It is grasped with one of the legs. The trap-thread either swirl in a circle or is aimed at the insect or prey flying nearby.

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QUESTIONS

1. Define species. Discuss the role of isolation in origin of species.
2. Discuss isolation as a factor of evolution.
3. What is geographic isolation ? What is its significance in formation of new species?
4. Define isolation and natural selection How the two help in the process of evolution.
5. Write short note on (i)Speciation (ii) Sympatric speciation
   (iii) Biston betularia
   (iv) Differential reproduction of gene.
6. Gige reasons why a harmful character of sickle cell anaemia is still persisting in human population ?
   Why it has not been eliminated by natural selection ?
7. Differentiate between:
   (i) Geographic and reproductive isolation.
   (ii) Hybrid inviability and hybrid sterility.
   (iii) Allopatric and synpatric speciation.
8. Discuss role of polyploidy in origin of new species.
9. Define the following:
   (i) Species (ii) Gene pool
   (iii) Speciation   (iv) Gene flow
10. Explain the terms :
    (i) decay of varcability
    (ii) Scattering of versability
11. Write a note on role of Genetic drifts in evolution.
12. Explain with suitable example, 'Genetic drifts reduce genetic variablity in populations.'

□ □

Human Evolution

HISTORY

In 1863, T.A HUXLEY made a scientific attempt to the problem of man's origin in his book *"Man's place in Nature"* and established that our closest relatives are apes. Later, in 1871, CHARLES DARWIN published his idea about man's ancestory in the book *"The Descent of Man"*. Both these ideas were misunderstood and it was widely publicised that man has

The discovery started by Dutch anatomist, EUGENE DUBOIS, who unearthed the ever first fossils of some ancestor of man from Solo Rive in Java. The fossil was just a small piece of human jaw bone and a partial skull. After this, W.C PELRAYMOND DART, LEAKEY and CLARK etc. made scientific contribution of the fossil records of man. Biochemical studies to trace similarity between ape and man indicate that man's closest relative is chimpanzee.
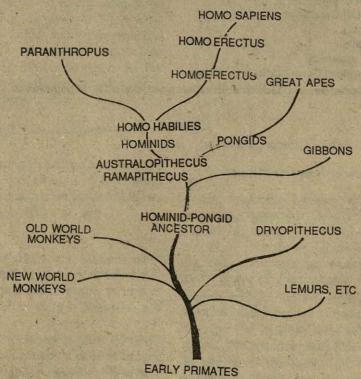
Fig.43.1. The Human Tree

descended from apes. With this idea of evolution of man a search was made to find out the 'missing link' either an original creature or its fossils which could be a link between man and ape.

Scientific study of human origin and evolution is only about one hundred years old and the most prehuman fossils have been discovered since 1920.

Place of Orgin of Man

Man has originated in central Asia, China, Java and India (Siwalik Hills).

TIME OF ORIGIN OF MAN

Mammals evolved from reptiles in early Jurassic period about 180-200 million years ago. These diver-

sified and occupied different parts of earth only after the extinction of Dinosaurs. Primates evolved about 65 million ago near the beginning of Triassic period. These were represented by shrew-like forms that competed with rodents for food and shelter. Some of these took to arboreal habitat and rest became extinct. During Palaeocine and Eocene this primate stock evolved into lemur and tarsier-like forms. Anthropoid apes or ancestors of monkeys, apes and humans evolved about 36 million years ago and the *hominids* (ancestors of apes and man) evolved about 24 million years ago.

PLACE OF HUMAN IN ANIMAL KINGDOM

LINNAEUS gave the two worded scientific name to man *Homo sapiens* (meaning *wise homonid*). He placed man alongwith monkeys and apes in order *Primata* and class *Mammalia*. Apes are represented by two families-1.*Pongidae* which include Chimpanzees, Gorillas and Orangutans and 2.Hylobatidae which includes gibbons. Humans belong to family *homonidae*.
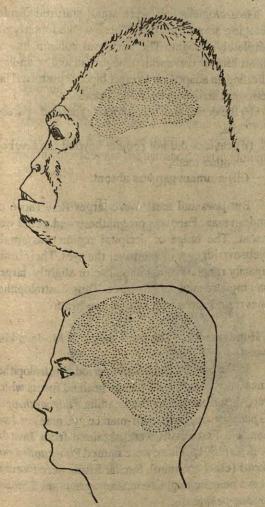
Fig. 43.7 The comparison of brain in gorilla and in man
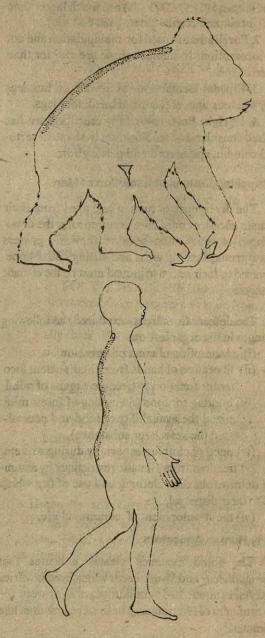
Fig. 43.2 The backbone of the ape forms a simple curving arch. In the bipedal human, it has an S-shaped curve due to erect posture.

Living apes and man are very similar except for few differnces which are developed in humans for bipedal locomotion. The main differnces are:-

Similarities between Ape and Man

1. **Brain and Cranial Cavity**–Human brain and cranial cavity (1350-2000 c.c.) are much larger than ape's brain and cranial cavity (450-600 c.c.).

2. **Forelimbs** are used for manipulation and not for locomotion. In humans these are shorter than those in apes.

3. **Bipedal locomotion**–Men walk on hindlegs only whereas apes still depend on all four legs.

4. **Upright Posture**–A fully erect posture has caused considerable modification in shape of vertebral column, spinal cord and pelvic girdle.

Compelling Causes of Evolution of Man

The divergence of human and apes from their primate ancestors must have occurred after the development of brachiation because they still possess broad trunk, flexible arms and strong collar bone. What led to their return to ground must be the climatic changes.

The descent from trees introduced the following changes in the organization:

(i) assumption of erect progression,

(ii) liberation of hands from their ancient loco motor function to become organs of mind,

(iii) hunting for food (dwindling of forest mini mized the availability of food and necessitated the search for substance),

(iv) need of clothing especially during winters,

(v) freedom from climatic restrictions by assuming omnivorous diet, clothing and use of fire which led to their dispersal,

(vi) the development of communal life.

Early Human Ancestors

The fossil evidence clearly indicates that *Ramapithecus* and *Sivapithecus* which lived in Africa and Asia (about 10-15 million years ago) were the forerunners of Homonids. These were first man like primates.

The first fossil of *Ramapithecus* was a fragment of upper jaw from Siwalik Hills of India, *Ramapith-ecus* and *Sivapithecus* possessed many pongid traits. These had short face, small brain case, thickly enameled large teeth an walkedn their knuckles.

EVOLUTION OF MAN IN PLEISTOCENE

1. Australopithecus (The first man-ape)
(Latin *australis*-south and *pithecus*-ape)

Its fossils were described by RAYMOND A.DART in 1925 from South Africa. These were intermediate between *Ramapithecines* and genus *Homo*. More fossils were found from Tanzania, Ethiopia and Kenya. These were about three million years old and were named *Australopithecus afarensis*. These are considered to be ancestral to all later hominids of genus Homo.

Australopithecines were small statured forms averaging about four feet. These walked nearly or completely straight. The vertebral column had a distinct lumbar curve with pelvis broad and basin-like indicating an adaptation to erect bipedal posture. The teeth were strikingly man-like because :-

(i) the dental arch was smoothly rounded parabola,

(ii) canines did not project beyond the level of other teeth,

(iii) a simian gap was absent.

But jaws and teeth were larger than those of modern man. Face was prognathous and a chin was absent. The bulge of occipital region was small. Eyebrow ridges projected over the eyes. Their brain capacity ranged from 450-600 cc. or slightly larger than modern adult Chimpanzee. Thus Australopithecines represented man with an ape-brain.

2. Homo erectus (The fore runner of Modern Humans)

In the Middle Pleistocene period, Australopithecines were succeeded by large brained forms which were described under the heading *Pithecanthropus* (G.*pithekos*, ape, *anthropos*-man i.e ape man) or Java man. It's first fossils were obtained from Java by DUBOIS (1891). These were named *Pithecanthropus erectus* (erect ape-man). Similar fossils were found in a cave near Peking, China, and were named *Sinanthropus pekinensis*.
MAYER (1950) has replace these names by Homo erectus.

Fig. 43.3 Java Man.

1. **Java Man** (*Homo erectus* = Pithecanthropus erectus) - Its fossils occured in the Pleistocene deposits some 500,000 years ago. Its cranial cavity was about 940c.c. intermediate between that of Australopithecus (600-700 c.c.) and modern man (1400-1600 c.c.). Its was more than five feet tall with skeleton much like ours. Its forehead was low and slanting, the face was prognathous, and jaws were massive with huge teeth. The chin was absent and bony eyebrow ridges were present over the eyes. He might have learned the use and construction of tools and lit fire.

2. Peking man(Homc erectus Pckinensis=

Pithecanthropus Pekinensis-Sinanthropus Pekinensis).

Fig. 43.4 Restoration of head of Peking man

These lived most probably 500,000-2,00,000 years ago. It is very similar to Java man with heavy bony eyebrow ridges, low slanting forehead and chinless face. But their cranial cavity was much larger than Java man ranging from 850-1200 c.c. and averaging 1075 c.c.

TRANSITIONAL FORMS

Some transitional forms connecting *Homo erectus* with *Homo sapiens* have been uncovered from Europe.

1. **STEINHEIMIAN SKULL.** Its skull is found from Steinheim in Germany. Its cranial capacity was about 1100 c.c. It had heavy eyebrow ridges and a high forehead.

2. **SWANSCOMBE SKULL.** This is known from three bones which form roof and back of the brain case. The bones are unusually thick. Its cranial cavity is about 1320 c.c. In other features it resembled *Homo sapiens*.

The above two skulls were obtained from the 2nd interglacial period.

3. **FONTECHVADE SKULLS.** These were discovered from Southern France from the 3rd interglacial period. The skull bones are unusually thick. But the skull lacked heavy eyebrow ridges and had cranial capacity even greater than 1400 c.c.

4. **EHRINGSDORE SKULL.** It was found from Germany and had a cranial capacity 1450 c.c. The skull had a fairly high forehead but with heavy eyebrow ridges. Thus it resembled Neanderthal man in eyebrow ridges and *H. sapiens* in forehead.

3. Homo sapiens (Late Pleistocene Man)

Homo erectus were succeeded by early *Homo sapiens*, which were described under different names as *Homo neanderthalensis, Homo heidelbergensis, Swanscombe man* etc. But, since these appear to be very similar, now they are grouped under *Homo sapiens*.

The fossils of primitive man were found in Europe, Asia and Africa. These are Heidelberg man, Neanderthal man, Solo man and Rhodesian man.

1. **Heidelberg man.** It is known only from a massive lower jaw, which was found from Heidelberg, Germany. The Jaw is large and heavy and lacks a chin. Teeth are like those of modern man. **Heidelberg** is regarded as an ancestor to Neanderthal man and contemporary to Homo erectus.

2. **Neanderthal man.** These are considered to be on direct line of ancestry of modern man. Their fossils were found in the Neanderthal valley in Germany. Previously it was named as *Homo neanderthalensis*. But according to modern concept these are known as *H. sapiens neanderthalensis*. These arose some 150,000 years ago and flourished in Europe, Asia and North Africa, but became extinct about 25,000 years ago. These were similar to us below the neck, and were heavily built with outwardly curved thigh bones.

The skull bones were thick, forehead was low and slanting and the eyebrow ridges were heavy. The jaw was deep with no chin. The cranial capacity was about 1450 c.c.roughly equal to that of modern man. But its lower and posterior portions were larger than the upper and anterior parts.

progress either in agriculture or in domestication of animals.

Most probably, these were wiped out by their more advanced cousins, the **Cromagnon man** about 35 thousand years ago or they were absorbed into the gene pool of modern man by interbreeding.

Rhodesian man (Homo rhodensis)-- Fossils of Rhodesian men were found in Rhodesia in the large limestone cave. This skull had a cranial cavity about 1300 c.c. with receding forehead and heavy eyebrow ridges. It might be even more primitive than Java man.

Cro-Magnon Man. These lived during last 30,000 years or more in Europe. These succeeded Neanderthals and became extinct about 10,000 years ago in the last glacial period.

Cro-Magnons were about 180 cm. in height with a large skull, broad face, rounded forehead, narrow nose and a prominent chin. They lacked eyebrow ridges. The cranial cavity was about 1660 c.c. These were cave dwelling and hunters. These were conversant with art and sketched pictures of their contemporary animals. They made tools from finely chipped stones. The tools consist of spearheads, and arrows. They made ornaments from ivory and decorated their body. They knew the use of hide of animals. They did not know agriculture and domestication but exhibited some cultural advance.

Fig. 43.6 Restoration of skull and head of Neanderthal man

It was quite intelligent to use and construct flint tools. It buried its dead and is supposed to perform ceremonies, constructed hut like dwelling structures. It is contemporary to modern man, but it made no

Fig. 43.7 Cro-Magnon Man

Modern Man (*Homo sapiens sapiens*)- After last glacial period i.e. about 10,000 years ago, *Homo-sapiens-sapiens* appeared and began to spread all over the globe. He learned to cultivate plants and domesticate animals of economic importance. These were the first settlers who started living a settled life.

CULTURAL EVOLUTION

The expanded mental abilities of humans is largely responsible for the development of culture.
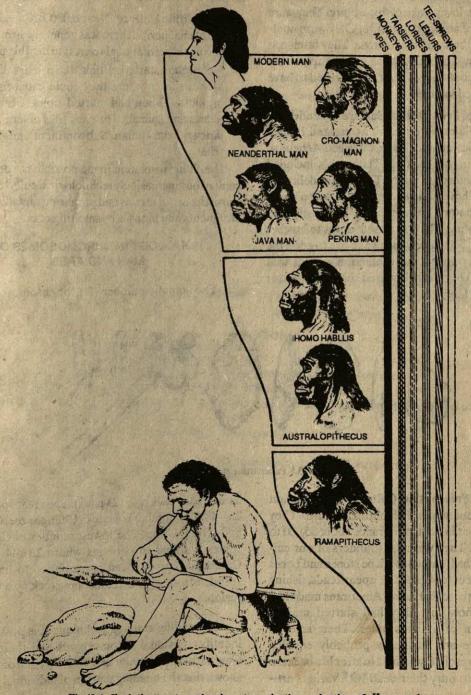
Fig.43.6. Evolutionary tree showing stages in the evaluation of *Homo sapiens* .

Human evolution, is charted in part through cultural evolution, primarily fabrication and use of tools. Most probably *Homo habilis* was first hominid tools maker.

1. **Lower Palaeolithic Culture.** *Homo-erectus* created the lower palaeolithic culture. They were founders of aboriginal culture. They were hunters and gathers and omnivorous. They fashioned crude stony tools like hand axe, scraper from rocks or from flakes. They are believed to have a primitive language.

2. **Middle Palaeolithic Culture.** Neanderthal man and later Homo sapiens created middle palaeolithic culture. They established Acheulian tradition in tool-making. Their tools included scrapers and spear points. These were delicately shaped. They had invented long wooden spear with sharp stone tip for hunting. They used to do group hunting. They possessed knives to butcher carcasses. They knew the use of fire to cook the meat, for warmth and protection against wild animals. They probably used animal hides for crude clothing.

facts. They had learnt to make paints and knew drawing and painting.

Cro-Magnon were one of the many human population that developed the Palaeolithic culture in Asia and Africa too. These had started settling down in permanent communities where food was abundant.

4. **Neolithic Culture.** Near 8,000 B.C. *i.e.* during 4th glacial period there was general warming of earth and retreat of glacier. During this period people had started settling down near lakes and ocean shores where they could catch fish and molluscs. They had started domestication of plants and animals. The early sites of farming are known from Indian Subcontinent and Middle East.

Neolithic revolution made possible the development of our increasingly technological culture. They learnt the use of metals and preparing metallic tools, ornaments and utensils by smelting ores.

HOMOLOGY IN CHROMOSOMES OF MAN AND APES.

The somatic number (2n) of chromosomes in

Fig. 43.8 Palaeolithic stone tools

3. **Upper Palaeolithic Culture.** Cro-Magnon man present upper Paleolithic culture. They lived in caves in Southern France about 35,000 to 8,000 B.C. They were the founders of our culture. They had learned to shape stones and bones into excellent tools, such as spearheads, fishing hooks like those that native Americans made and needles show that they had started making clothes out of animals hides. Their level of intelligence and humanity probably equaled ours. They probably belived in after life because they used to bury their dead with various arti-

human body cells is 46 (23 pairs). The great apes have $2n = 48$. The number is same in Chimpanzee, Gorilla and Orang Uttan. The lowest number of chromosomes is found in Gibbons where $2n = 44$ and in Catarrhini $2n = 42$. Man is presumed to have descended from a 48 chromosome stock by a centric fusion.

By banding-staining technique it is possible to identify individual chromosomes and their parts. Comparison of human and ape chromosomes has shown that the banding pattern of individual human

450

Chromosome 3   Chromosome 6

A   B   A   B
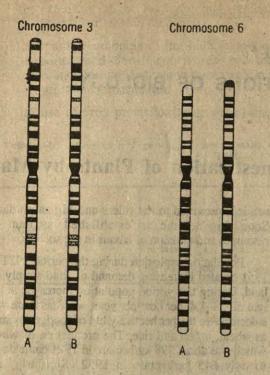
Fig 43.10 Choromosomes 3rd and 5th of Man and Chimpanzee showing similarity in the banding pattern.

chromosomes is very similar and some instances identical to the banding pattern of apparently homologues chromosomes in great apes. Fig.43.16 shows the banding pattern of chromosome No.3 and 6 of man and chimpanzee. The remarkable similarity in the bands of these chromosomes indicates a common origin of man and chimpazee.

The number and gross morphology of chromosomes in different human races is the same. This shows that morphological differences in the human races are very insignificant from evolution point of view.

In 1971, BILL HOYER, DAVID KHONE and others compared the similarity in the DNAs from different species of great apes and man by DNA-DNA hybridization method. This indicates the similarity in the nucleotide sequence between the DNA molecule of two species. There exists 2.5 % difference between DNA of chimpanzee and man. Difference in the DNA of man and moneky is about 10 percent. This indicates that DNA of human beings is very closely related to chimpanzee, less closely to Gorilla and still less closely to monkeys.

QUESTIONS

1. Give an Account of fossil history of man.
2. Trace trends in human evolution with particular reference to recent fossil records.
3. Summarize the compelling factors responsible for human evolution.
4. Conceive possible modification in the organisation associated with bipedal locomotion and erect posture based on human evolution.
5. Summarize differences and similarities between great apes and man.
6. Differences between:
     (i) Paleolithic and neolithic culture.   (ii) *Australopithecus* and *Homo erectus.*
     (iii) Cro-Magnon man and Neanderthal man.

7. Mark the correct statements:-
     (i) Man has descended from apes.
     (ii) Evolution of mammals occured in mesozoic era about 200 million years ago.
     (iii) Loris and lemur belong to Anthropoid apes.
     (iv) The first fossil of man-like forms were described by EUGENE DUBOIS in 1891.
     (v) Australopithecus are the first ape man.

8. Write notes on :
     (i) Sivalika hills   (ii) Similarities between apes and man
     (iii) Homology in the number of chromosomes of man and ape.   (iv) Paleolithic culture.
     (v) Neanderthal man

9. Fill in the blanks :
     (i) Fossils of Ramapithecus were obtained from————.-------------.
     (ii) Simian gap is the space between ------------------and premolars.
     (iii) The size of cranial cavity in present human beings (*Homo sapiens*) is -------------- c. c.
     (iv) Homo erectus erectus is the name given to --------------- by Mayer.

UNIT 5

PRACTICAL APPLICATIONS OF BIOLOGY

CHAPTER 44

Domestication of Plants by Man

About 2 million years ago, the early paleolithic man was a nomad who started using weapons for hunting. Later, he began eating fruits of wild plants. Habitations: As he learnt to control fire and developed tool-making, the settle life began. This was followed by cultivating plants near his habitation.

The earliest human civilisations that started growing plants were around the river Nile in Egypt, the Chinese river valleys and the northern Indian plains. The fertility of soil and availability of plenty of water in these areas best suited the conditions for raising the crops. The plentiful agricultural production helped the people of these areas to become self-sufficient and to enable them to build great civilisations, the rem-hants of which still exist.

The earliest records of human civilisation which grew crops like wheat, barley and rice are found in Indus Valley. The historians are of the opinion that these civilisations existed about five to six thousand years ago. This indicates that skills of agriculture were developed by man several thousand years back. The Aryan tribes of Central Asia which invaded India knew the skills of agriculture, especially the use of bullocks and plough, and management of cattle. They soon spread all over the north Indian plains and further up to the extreme South.

Once the Aryans settled in India, an agarian society of a distinct type got established throughout the country, and division of land and labour started. Initially the land was owned by the kings and later by the Zamindars or other land-owners. The land was cultivated by villagers who derived their bread, and also contributed the revenues which supported the states and the officials. Small pieces of land to practise agriculture were given to carpenters, weavers, blacksmiths, etc., in return for various services provided to the rulers and big zamindars. Soon this became an established system of resources and division of labour in the society.

Population explosion during the period 1921 to 1951 created increasing demand of food supply on land. During this period population increased at the rate of 1.3–1.4 per cent per year, whereas there was a decrease in the per hectare yield of foodgrains such as wheat, millet and rice. The production of wheat which was about 798 kg/hectare in 1921 came down to only 645 kg/hectare in 1952. Similarly, the production of rice came down from 1058 kg/hectare in 1921 to 800 kg/hectare in 1952. To meet the demand of food supply of the ever increasing population of the country, concerted efforts were started to increase the yield of foodgrains, and cultivate the arid land. Several agricultural programmes were opened and agricultural projects started. Research centres were established to develop high yielding and disease resistant varieties. Utmost importance was given to irrigation and fertilisers were made available to the farmers at subsidized rates. This enabled the country to achieve self sufficiency in food for the last several years.

The yield of wheat and rice which stood at 668 kg and 663 kg per hectare respectively in 1952, increased to 1851 and 1468 kg per hectare in eighties. There is still a great deal of scope to increase our food production. The increased area under irrigated cultivation along with improved varieties of seeds, intensive cultivation, easy availability of fertilisers and raising of more than one crop have led to the "Green Revolution". The factors resulting in the Green Revolution, thus making our country not only self sufficient but also surplus in the matter of foodgrains can be summarised as given below:

(a) development and introduction of high yielding varieties of crops,

(b) extension of the high-yielding varieties over larger areas in the country,

(c) multiple cropping, using high, inputs of water and fertilisers which provide economical yield of two to three crops in a year from the same field,

(d) use of crop protection measures against diseases and pests, and

(e) transfer of the technology of scientific farming from research farms to village farmers.

The green revolution has enabled us to achieve the following targets in the case of major crops:

Table 44·1: *Projected Figures for area, yield and production as compared for the years 1970-71, 1980-81 & 1983 - 84*

Crop	1970–71			1980–81			1983–84		
	Area in lacs hectares	Yield kg/ hectares	Produc- tion lacs tons	Area in lacs hectares	Yield kg/ hectares	Produc- tion lacs tons	Area in lacs hectares	Yield kg/ hectares	Produc- tion lacs tons
1. Cereals	1018	949	966	1042	1190	1142	1069	1299	1389
2. Pulses	225	524	118·2	224·5	473	106	234	541	126·6
3. Sugar Cane	26·15	48,322	1264	26·67	57,·844	1542·5	31·67	55,904	1770
4. Cotton *	76·0	106	47·6	78·2	152	70·10	77·6	144	65·8
5. Oil seeds	166·4	579	96·3	176·0	532	93·72	186·9	685	128·14

* Bales of 170 kg each

Source :– Economic Surveys of relevant years.

The green revolution as a result of agriculture research, development of high yielding and disease resistant varieties of seeds has brought about tremendous change in the traditional village life. The village is no longer a self-contained unit with its traditional relationship between the land-owners, the tillers, the money-lenders and the local artisans. Now the villages are getting increasingly linked with the outside world through the inputs they require in terms of fertilisers, pesticides, seeds and irrigation facilities, knowledge and skills and through the outputs of production. The transport of inputs and outputs along with the storage and distribution of the surplus, has created a need for the construction of roads, godowns and the repair facilities. Nationalised banks have opened their branches in the villages to provide credit to the farmers.

The story of man's domestication of plants has reached to such a stage that even now agriculture dominates the national economy. It provides employment to more than three-quarter of the total labour and accounts for more than 50 per cent of the national income. To feed about 1.5 crores new mouths every year we must continue efforts to increase our agriculture produce on the following lines:

1. Maximum use of high-yielding varieties of cereals with greater attention to improving their quality further.

2. Intensive efforts to raise yield of major commercial crops.

3. To provide and expand irrigation facilities.

4. Greater availability of fertilisers, plant protection materials, farm machinery and credit facilities.

5. Improvement in the existing agricultural marketing system for the benefit of the farmers and assurance of minimum price for their produce.

Additional Resources of Food In near Future

Keeping in view the more distant needs of man in future, it is essential to analyse the present situation. All the organic food on the earth is directly or indirectly derived from the photo-synthetic activity of green plants. Of nearly 360,000 plant species known so far only a handful are used as sources of food. Amazingly, only a dozen or so provide more than 90 per cent of the total global food supply. We will have to change our food habits and explore other plants if more could be added to this list. New strategies are to be worked out in order to bring arid land under cultivation. This accounts for about a third of the earth's habitable area. By bringing arid land under cultivation, we would be able to support many more. An improved irrigation management and fertiliser facilities will transform the arid zones into green fields. The key to success in this direction lies in a collaborative research on a large scale throughout the world.

Three-fourth of the earth is covered with water, where grow the phytoplankton. The phytoplankton accounts for 90% of the photosynthesis, thus many times greater a producer of organic matter on the earth than all the land plants put together. Man consumes only a few phytoplanktons as food (for example, sea kelps and some red algae) besides fishes and other marine animals. Much greater quantity of food could be made available to us if some suitable processing technology is developed to tap this vast resource of organic matter growing unnoticed in the oceans. But with the seas getting increasingly polluted in recent times, more concerted research and action plan would be necessitated to achieve a breakthrough.

Man has still a long way to go in his venture to domesticate plants for his ever growing population. The scientists are trying to harvest proteins and other foods, directly from foliage and waste plant material. Efforts are on to obtain proteins and carbohydrates from the phytoplankton so as to make the ocean the potential source of food for the human race.

QUESTIONS

1. Give a brief account of the history of origin of agriculture.
2. What do you mean by 'Green Revolution'. Discuss the factors that contributed to its success.
3. Discuss briefly the future resources of human food.
4. What were the reasons that the earliest human races settled in the great river valleys ?
5. In what ways the agricultural development has brought about a change in our rural scene ?
6. Describe briefly agricultural development in India.
7. Fill in the blanks in the following :—
   (a) The early man learnt the use of weapons for ....
   (b) The agriculture was started in the Indus Valley about .... years ago.
   (c) Oceans are the potential source of food supply because .... of the world's photosynthesis takes place there.
   (d) The earliest man started consuming .... as food.

Improvement of Crop Plants
(Plant Breeding and Plant Introduction)

Breeding of domestic animals and cultivated plants to get better or improved varieties has been practised by man from time immemourial, much earlier to the discovery of Mendel's Principles of Inheritance. With great increase of knowledge in the field of genetics, there is every season to expect an acceleration is the rate of improvement. No doubt, genetic principles have been fruitfully applied to both animal and plant breeding and a number of new animal and plant races have already been established, the work is still in progress and a number of research centres are actively engaged in this field.

PLANT BREEDING

History

Man has been cultivating useful plants since prehistoric time. The primitive man was growing several of our food plants like wheat, barley, rice, mango, apple, banana, datepalm and onion and the fibre plants like flax and hemp etc. More than 2,000 years ago Asians cultivated beet, carrot, garden-pea, oats, rye, sugarcane, etc.

Since the early days, no significant addition has been made to the list of cultivated plants but great improvement has been made in the quality and varieties of economic plants already under cultivation. In fact, man has been attempting to improve his crop plants since prehistoric times. It was being achieved purely by selection. But this was just a hit and miss method without proper knowledge of the inheritance of different characteristics.

Plant Breeding Research Centres in India

Plant breeding is concerned with the improvement of economic plants so as to increase the agricultural production with the development of new varieties of economically important plants. In India plant breeding is actively carried out at *Indian Agricultural Research Institute, Delhi; Central Potato Research Institute, Shimla; Rice Research Institute, Cuttak; Sugarcane Research Institute,*

Coimbatore and at a number of Agricultural Universities and research stations.

Definition

Plant breeding as a science is of recent origin. It can be defined as follows:

Plant breeding *is the science of improvement in the hereditary characters of crops and production of new crop varieties which are far better than original varieties in all respects.*

Objectives of Plant Breeding

The aim of plant breeding is to develop a variety which combines as many of the desirable and beneficial characters of economic value as possible. Some of these are –

1. Increase in the yield. Directly or indirectly man depends for his food entirely on plants. Milk, butter, eggs, and meat that are obtained from animals are ultimately derived from plants because the animals giving us all these articles, feed on plants. To provide proper food for ever increasing human population the world over, is the most serious problem. Despite great improvements in the methods of agriculture, improved irrigation, an extensive use of fertilisers to increase its productivity (fertility) and increase in land area under cultivation, the food produced is not sufficient to meet the requirements of people the world over.

Keeping this problem in mind, the plant breeders have developed new varieties of crop plants that can give higher yields of cereals, fodder, fibre, oil, sugar, pulses and other plant products.

2. Improved quality. Quality of the plant produce determines its suitability for various user. Quality characters vary from one crop to another, *e.g.* grain size, colour, milling and baking quality in wheat; cooking quality in rice; malting in barley; size, colour and flavour in fruits; keeping quality and size of vegetables; protein contents in pulses

and higher sugar content in sugarcane.

3. Agronomic characteristics. Modification of characteristics such as plant height, tillering, branching, erect or trailing habit etc. are desirable. Thus dwarfness in cereal plants is generally associated with lodging resistance and responsiveness for fertilisers.

4. Adaptability to new regions. Development of plants not sensitive to photoperiod has permitted wheat and rice in new areas. Rice is now grown in Punjab and wheat in West Bengal.

5. Varieties suited to particular soils and climates. Same variety of plants cannot grow successfully in different types of soils and in different climatic conditions. It is, therefore, essential to develop varieties that are suited to new agricultural areas. For example, the groundnut was cultivated exclusively in Gujrat. Development of several new varieties of groundnut like C-158, C-117, C-145 and C-116 has made its cultivation possible in the sandy and baran soil of Punjab.

6. Resistance to disease and insect pests. Crops are damaged and destroyed by several diseases and insect pests. For example, black stem rust may completely destroy a field of wheat. Potato blight is caused by *Phytophthora infestans* which was responsible for the potato famine in Europe in 1945-47.

Considerable efforts have been made to develop varieties which are immune to the diseases. For example, Sharbati wheat of M.P. is rust resistant. Wheat varieties C-250 and C-228 are resistant to yellow rust.

7. Change in duration of maturity. It permits new crop rotations. Development of wheat varieties suitable for late sowing has permitted rice-wheat rotation. Breeding of early maturing crops suitable for different periods of sowing is an important objective.

8. Elimination of toxic substances. Some plants have toxic substances which must be eliminated to make them safe for consumption. For example, khesari pulse has a neurotoxin, β N-oxalylamine (BOAA) that causes paralysis and *Brassica* oil has erucic acid which is harmful to human health. Removal of such toxic substances would increase the nutritional value of these crops.

9. Salt Tolerance. Development of varieties for saline soils would be helpful in increasing crop production in India.

10. Resistance to lodging. High yield crop plants have a tendency to lodge under conditions of increased irrigation or greater application of fertilisers. This adversely affects the quality and quantity of plant products. Resistance to lodging is a character which should be developed in crops with high yield.

METHODS OF PLANT BREEDING

Plant breeding involves the improvement of economically important plants by scientific methods. These methods are related to reproduction. It is, therefore, necessary to take into account the methods by which plants in question propagate. Some plants propagate asexually by vegetative structures while others sexually. Sexually reproducing plants may be self-pollinated or cross-pollinated, whatever may be the mode of reproduction the three steps involved in plant breeding are:

1. Introduction of mutations and variations

2. Selection

3. Hybridization

1. Introduction of Mutations and Variations

(*a*) **Mutations.** Mutations are sudden heritable variations in plants which develop due to rearrangement of genes (*gene mutation* or *point mutation*), changes in chromosome size and structure (*chromosomal mutation*), changes in the chromosome number (**polyploidy**) and changes in the body of the plant (*somatic mutation*). These include all types of hereditary changes in genotypes of plants.

Mutations are in exhaustible source of new variations which provide material for recombination and selection for plant breeding. Mutations may arise spontaneously, may be incorporated in the existing variety by hybridization or may be induced by mutagenic agents like atomic radiations (X-rays, ultraviolet rays, radioactive isotopes) or certain chemical reagents like mustard gas.

Some mutations occur in the vegetative tissues of plants like buds either naturally or may even be induced artificially by gene mutations or

chromosomal mutations. Selection of such varieties and their propagation by vegetative reproduction leads to improvement of varieties.

   (b) **Polyploidy.**– Change in the chromosome number had played an important role in the origin of new varieties and species of economic importance. The simplest of autoploids are *triploids* which can propagate only by vegetative means. Many of our crop plants like wheat, oat, sugarcane, cotton, potato, grasses, forage plants, fruits and vegetables are natural polyploids. More than half of the cultivated plants are allopolyploids, the bread wheat is hexaploid.

   Artificial doubling of chromosomes by **colchicine technique** has opened up new fields for the production of polyploid plants and new varieties of crop plants.

   Induced mutations and variations have been responsible for increased rust resistance and baking quality in wheat, higher yield and mildew resistance in barley, superior fibre content and increased yield in cotton, and increased yield of seeds and oil in white mustard. Selection from somatic mutations has lead to improvements is ornamental plants like chrysanthemums and dahlias, crop plants like sugarcane and potato and fruit plants.

Though usually harmful, some mutations are found to be desirable or beneficial. For example in 1968 in India P.B. RAJU, a horticulturist of West Godavari district accidentally discovered a mutant variety of banana in his farm which bore golden coloured banana about 14 inches long and 2-5 inches in diameter and about 150 banana per bunch. The bananas were more delicious than the ordinary table variety. The giant variety of gram (*Cicer gigass* and of groundnut (*Arachis hypogea*) are improved varieties arising through mutation. The **Sharbati Sonora** variety and several other varieties of bread wheat have been developed by induced mutations and selection.

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2. Hybridization

   Hybrids are known for their vigour, growth size and yield. The hydridization started with the development of new maize varieties, but hybrid varieties of bajra, jowar, sugar, beets, onions, tomato, grasses and vegetable crops, have also been developed. The procedure involves the following steps:

(1) **Selection of desired plants** in the open pollinated population,

(2) Selfing the selected plants through several generations to produce uniform homozygous inbred lines, and

(3) Crossing the selected inbred lines to produce uniform F_1 population in such quantities, and that F_1 seeds can be grown directly.

   The hybrids produced in this way are superior to the homozygous inbreds and often excel the natural populations. The following three methods of hybridizations are in practice :

(*i*) **Single cross method** – Two inbred lines are intercrossed and the hybrid seeds are used for raising the crop.

(*ii*) **Three way cross** – This involves three inbred lines A, B and C. Two of them are crossed (A×B) and F_1 hybrid is then crossed to the third (C). The F_1 individuals are taken as females and the third parent as the male. The origin of hexaploid emmer wheat is an example of such a cross.

(*iii*) **Double croos method** – This method involves bringing together the genes from four lines. Parents A and B are crossed to get F_1 hybrids. Same way parents C and D are crossed separately. The F_1 hybrids of these two lines are then crossed to each other. This double cross method has been exploited in case of maize.

   Sometimes, hybridization between different species followed by segregation results in the production of improved varieties. These can not reproduce sexually, however these can be maintained by vegetative methods of propagation such as budding or grafting.

3. Selection

   Selection is an important step in all breeding experiments and has been practised by man since the early days of agriculture. The selection involves picking up the better ones out of the entire crop plants. The selected plants are separated from the inferior ones and are favoured by reproducing them under controlled conditions. There are two patterns of selection.

(1) Single plant or Pure line selection – The single plants with desired trait or traits are selected out of the variable population in the field. Seeds from selected plants are sown in separate rows to produce a progeny. Desired plants are again selected from this progeny. Seeds from these plants are again sown separately. This is continued for several generations. The inferiors are eliminated each generation. Wheat varieties like Kalyan-227 and PV-18 have been developed at Ludhiana by this type of selection.

(2) Mass selection – In this selection a number of similarly appearing plants are selected for the desired trait and their seeds are mixed together. The mixture of seeds so obtained is sown to raise the new crop. By such a selection general level of population is improved.

PLANT INTRODUCTION

The process of introducing new plants from their growing place to a new locality with different climate is termed as **plant introduction**. The adjustment of such plants to their new locality is called **acclimatization**. The new crops or the new varieties may be introduced in the form of seeds or cuttings. In vegetatively propagated crops the cuttings are imported and in sexually propagated crops the seeds are imported. In the latter case, the cross-pollinated plants are introduced since in them there is greater frequency of gene recombinations owing to frequent cross-pollination. Some of the recombinations may be more favourably adapted in the new environment. The plants may be introduced into a locality either from outside the country or from different regions within the country.

For introduction of plants from outside the country, permission is taken from the concerned country through the plant introduction organisation. Before entering the country, it is inspected at the entry point according to quarantine rules.

Table 45.1: List of Some Important Improved Varieties of Cereals

1. **Wheat**

1. N.P.718	2. N.P.799
3. C.591 of Punjab	4. RS.31-1 Rajasthan
5. Lerma Rojo	6. Sharbati Sonora
7. Sonalika	8. Hyb 65 of M.P.

2. **Rice**

1. Basmati 307	2. I.R.8
3. B.R.41	4. B.R.46
5. Co.4	6. Co.25, 26
7. S.1092	8. SR.26B.

3. **Maize**

1. T.41	2. Jaunpuri U.S.13
3. Ganga 1, 101	4. Ranjit
5. Deccan	6. Himalaya -123
7. Jawahar	8. Vijay & Vikram

4. **Jowar**

1. S.405	2. CSH-1
3. G.2	4. N.D.15

5. **Barley**

1. H.B.I.	2. Pusa Moti
3. AKP 2 of AP	4. RSJ of Rajasthan

Table 45.2: List of Important Hybrid Varieties of Oil Seeds

1. **Groundnut**

1. T.M.V.I.	2. T.M.V.2
3. Spanish improved	4. Kard 4-11
5. Big Japan	6. Faizpur 1-5

2. **Mustard**

1. B.R.13 & 23,	2. R.T.I.
3. B.85 of rai	4. B.54 of toria

3. **Sesame**

1. M.3-2 for Bihar	2. 128 for M.P.
3. B.14 for West Bengal	
4. 8 & 85 for Maharashtra	

4. **Linseed**

1. N.P.	2. T.1 & T.26
3. N.P.439 & 440	4. BR.40

Table 45.3: List of Important Improved Varieties of Cotton and Sugarcane

1. **Sugarcane**

1. CO.312, 313	2. CO.419, 421, 449
3. B.O.24	4. POJ 2878

2. **Cotton**

1. Andrews	2. Co-Pusa Egyptian
3. 170-CO_2	4. Indore-2
5. Laxmi	6. Busi & 394

If found suitable, permission is granted and handed over to the concerned institution. There it is grown under local conditions and tested for the acclimatization and presence of desired characters. It is, thereafter, used in hybridisation or as such grown and cultivated.

Introduction has been of great importance as a source of resistant material to some of our crops.

QUESTIONS

1. Why the mankind has felt the need to improve the crops ?
2. What are the different measures for improving the crops ?
3. Why is it necessary to cultivate a new variety before releasing it to farmers ?
4. How are mutations caused ?
5. What is the main objective of plant breeding and how can it be achieved ?
6. What is artificial selection ?
7. Write short notes on the following :-
   - (*i*) Hybridisation
   - (*ii*) Selection
   - (*iii*) Mutation
8. Explain the following :-
   - (*i*) Artificial selection
   - (*ii*) Natural selection
   - (*iii*) Introduction
9. Define the following terms :-
   - (*i*) Pure line
   - (*ii*) Acclimatization
   - (*iii*) Hybrid
10. Distinguish between natural and artificial selection.
11. Name two hybrid varieties of each :-
    - (*i*) Wheat
    - (*ii*) Rice
    - (*iii*) Barley
    - (*iv*) Potato

□ □

Pesticides and Pest Control

Various animals more particularly insects cause severe crop losses. They feed on crop plants and also damage the crop during the storage. The insects also feed on the plants as well as grains during the storage resulting often in severe losses. The intensity of pest-attack varies, which may lead to either partial or complete crop failure.

PESTICIDES

The concept of using chemicals for controlling insect pests is not new. But, its importance and popularity increased only after the discovery of DDT. Originally, these chemicals were classified on the basis of their mode of entry in the bodies of insects as follows –

(a) **Systemic insecticides.** — These persist in the plant body and continue insecticidal function for extended periods.

(b) **Contact insecticides.** — These are toxic to insects upon contact.

(c) **Fumigants.** — These produce vapours or fumes which are toxic.

(d) **Poison baits and traps.** — The insects, pests feed on them or get surrounded.

At present, the generally accepted classification is based on the chemical nature of the insecticides.

1. Inorganic Insecticides
(i) Arsenicals
(ii) Fluorilicates

2. Organic (of Plant origin)
(i) Nicotine sulphate
(ii) Pyrethrins
(iii) Rotenone

3. Synthetic –
(a) **Chlorinated hydrocarbons**
(i) Aldrin
(ii) BHC
(iii) DDT
(iv) Endrin
(v) Dieldrin
(vi) Chlordane
(vii) Methoxychlor

(viii) Endosulfan

(b) **Organo-phosphates**
(i) Parathion
(ii) Malathion
(iii) Phosphamidon
(iv) Dimethoate

(c) **Carbonates**
(i) Carbaryl
(ii) Isolan
(iii) Dimetilan
(iv) Carbofuran

At present hardly anyone of the inorganic insecticides are in use. Insecticides of plant origin have also been relegated to the background by the synthetics, and at present very little quantities are being used.

The use of synthetic organic insecticides has increased with leaps and bounds. BHC, DDT, Malathion, Parathion, Toxaphene, Pyrethrum, Nicotine sulphate, Methyl-demeton and Phosphamidon are commonly used synthetic organic insecticides.

Hazards in the use of Insecticides – Improper, excessive and careless use of insecticides is injurious to man and his domesticated animals. Proper safeguards are, therefore, necessary to protect the persons handling the insecticides, the crops to which they are applied, the consumers who have to use the produce of the treated crops, and the domesticated animals which feed on such produce, the pollinating insects, the parasites and predators of insects, the fish, birds and other wildlife preying upon insects, likely to be affected by coming into direct or indirect contact with the insecticides applied. Also, the pollution of air, soil and water is to be avoided as far as possible.

INTEGRATED PEST MANAGEMENT

Integrated Pest Management involves cultural controls to insure continued production of soil without the excessive use of synthetic pesticides. These are –
(i) rotation of crops and

(ii) improved sanitation practices.

The above methods often avoid pest problems. Starvation also helps in eliminating the pests. a target crop may be planted to lure the insects away from the economic crop. Mixed planting is also used to cut down on the concentration of pest-attracting crop. These methods may be carried out with a modified spraying with only necessary amount of synthetic pesticides after partial control by biological methods has been achieved. Decreased usage of synthetic chemical pesticide in ultra-low volume spraying has also been found effective. By using safe and effective naturally occurring plant and microbial insecticides, the environment can be saved from agrochemical pollution.

BIOLOGICAL CONTROL

The latest trend in the pest control is to minimise the use of poisonous chemicals and achieve better effect through integrated methods involving a careful combination of biological, cultural and chemical methods.

Almost all cultivated plants are attacked by pests and all these pests have predators and parasites which attack them in turn. If the predators are voracious feeders then they eliminate a large number of pests at one stroke. On the other hand parasites breed either in or on the host and kill the pests slowly. The common insect predators are dragon flies, ant lions, praying mantis, lace wings, lady bird beetles, wasps and hoover flies etc. Most of the parasitic insects lay their eggs either on or inside the herbivorous insects and when the larvae emerge they feed on the caterpillars. Many hymenopteran and dipteran parasites behave like this. Bacteria are also used to deal with many animals.

Recent methods of biological control used are the sterile male technique and the use of sex attractants. Even unwanted plants and weeds can be controlled by the use of insect parasites. Thus there are five methods of biological control known to us to deal with animals and one on plants.

Control of Animals
A. Use of predators
B. Use of animal parasites
C. Use of bacteria or virus
D. Sterile male technique
E. Sex attractants.

A. Use of Predators

1. The hoover fly larve (Syrphid larvae) are very effective in keeping the aphids (Plant Bugs) under check as they feed on the aphids only.

2. The common solitary wasp not only preys upon the looping caterpillars but keeps them as food for their young ones also.

3. The fluted scale insect (*Icerya purchasi*) is a common pest on cirtus trees in foreign countries. This pest has somehow found its way to India and attacks the wattles and citrus trees in Nilgris and Kodaikanal. The natural enemy of the scale insects are the lady bird beetles (*Rodolia cardinalis*) of the family Coccinellidae. These beetles can be bred in captivity and released whenever there is a threat of scale insects. The control is very effective. The scale insect was a serious pest in California in the late 19th century when KOEBELE went all the way to Australia to find out its natural enemy, the lady bird beetle, which is called "vedalia" in California.

4. The mosquito larvae which thrive in ponds and pools are easily controlled by rearing the lavricidal fish *Gambusia*.

5. In the Hawain island the sugarcane leaf hopper is controlled by the capsid bug (*Cytorhinus mundulus*) and the sugarcane borer by the Tachnid fly (*Ceromasia sphenphori*).

6. The sugarcane scale insects are easily controlled by the coccinellid predators (*Cailochorus negriti* and *Pharoscymmus horni*).

7. Recently in Chengalpathu district of Tamil Nadu, *Procerus longiforceps* was used to tackle successfully the sugarcane internode borer *Chilosacchariphagus indicus*.

B. Use of Animal Parasites

1. *Nephantis serinopa* is the black headed caterpillar which is a dangerous pest on coconut palms. The pests eat away the green part of the leaves leaving only the central ribs resulting in the death and drying up of the palms. There are two hymenopteran parasites which attack this pest. *Perisierola nephantidis* attacks the larvae while *Trichospilus pupivora* attacks the pupa. These two parasites are very effective in controlling the caterpillar. They can be easily reared in the laboratory.

2. The wolly aphis (*Eriosoma lanigera*) which is very common in Europe got introduced into India and has become a regular pest on apple trees. The Hymenopteran parasite *Aphelinus mali* is very effective in controlling the wolly aphis.

3. The sugarcane internode borer *Chilo indicus* can be controlled by its parasite *Trichogramma australicum*. The caterpillars of the moths *Argyria stricticraspis* and *Emmalocera depresella* attack sugarcane and cause very damage. The natural enemy for this moth is hymenopteran *Trichogramma minutan* which is very small and is about 1 m.m. in size. Though small it attacks the eggs of the moths and destroys them. It is also easy to rear this parasite in the laboratory conditions by using the meal worm moth as the host material.

4. The **Ichneumon wasp** lays eggs inside most of the caterpillars. The eggs hatch out inside caterpillars and eat them up completely. The Ichneumon wasp thus forms an effective check on caterpillars.

C. Use of Bacteria or Virus

1. The Japanese beetle *Papillio japonica* is an extensive pest on many kinds of plants. Two species of bacteria *Bacillus popilliae* and *Bacillus lentimorphus* produce disease on this beetle. Milky disease proves fatal to the beetles. The use of these bacteria is very useful as they do not harm any other animal and one application has its effect for years.

2. In Australia when the Rabbit population increased and became a nuisance to agriculture a fatal disease called Myxomatosis was used to bring down the number of rabbits. The disease is caused by a filterable virus which is highly contagious among rabbits but does not harm man and other animals.

D. Sterile Male Technique

One of the modern methods of biological control is the sterilization of the male population of the pest so that its further multiplication is checked. The sterile technique for red weavil, the pest on coconut, was developed at the Central Plantation Research Institute at Kayankulam, Kerala. The male insects are sterilized by using gamma rays at the Bhaba Atomic Research Centre. The sterilized males are released in sufficient numbers in infected gardens. The sterile males mate with the normal females and cause the production of infertile eggs, thus cutting down the strength of the future population.

The sterile male technique was used in U.S. for controlling screw worm fly and for eradicating *Culex fatigens*. The same method can be adapted for *Anopheles* also. This experiment was tried by ICMR and WHO project at Dulasidaras, a village about 15 km. from New Delhi. As the female mosquitoes are fertilized only once in their life time, the sterile males are released in large numbers so that they will mate with the females before the normal males ever get a chance to mate with a female.

The use of the sterile males is more effective when the population is fairly low and has not reached the pest level at least in some areas.

E. Use of Sex Attractants

Many insects release chemical substances called *pheromones* which have a powerful attracting effect on the other sex during the breeding seasons. In one experiment, according to DEBACH it was found that a virgin female pine saw fly kept in a cage was able to attract about 11,000 males. It is also known that many female moths can attract males from long distances.

These natural pheromones and synthetic pheromones are now used to attract and lead insect pests to death traps. The orient fruit fly on Rota Island was successfully eradicated by the use of the synthetic sex attractant, Methyl Eugenol. In Florida the Mediterranean fruit fly was similarly eradicated.

In India a pilot project is going to be implemented in Bhatinda by the use of synthetic pheromone *Gossyplure H. F.* to tackle the pink ball worm which is a pest on cotton. If this proves successful this method of insect control will find new avenues of use in India.

The use of natural pheromones in the control of pests is no doubt a good method of biological control but if synthesised pheromones are used in its place then it becomes almost a case of chemical control.

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QUESTIONS

1. Why are biopesticides preferred to chemical fertiliser ?

2. What is biological control of pests? Discuss.

3. Write brief notes on the following :
   (i) Chemical pestisides
   (ii) Use of parasites in pest control
   (iii) Sex-attractants
   (iv) Sterile male technique

4. Match the items in Column I with those in Column II.

Column I	Column II
(a) Fluted scale insect	(i) Citrus trees
(b) Scale insects	(ii) Coccinellidal predators
(c) Sugarcane scale insects	(iii) Lady bird beetles
(d) Pheromones	(iv) Papillio japonica
	(v) Sex attractants

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Fertilisers and Bio-Fertilisers

FERTILISERS

Fertilisers have become a major factor in improved agriculture and increased production. Constant use of land leads to the loss of its important nutrients particularly nitrogen and phosphorus and thus loses its fertility. Chemical fertilizers in terms of nitrogen and phosphorous are applied to the land so that it regains its fertility.

The total consumption of fertilizers in our country is about 9.2 million tonnes and is expected to increase to about 20 million tonnes by the turn of 20th century. In India, the average consumption of fertilisers is about 35 kg. per hectare, whereas it is 300-350 kg. per hectare in Japan and Holland. Even China uses four times the amount of fertiliser that India uses per hectare of arable land.

Table 47.1: Per hectare yield and fertiliser use of Asian countries

Country	Fertiliser use (kg.) per ha.	Yield per ha. in tonnes Paddy	Wheat
India	37.8	2.07	1.80
Bangladesh	43.6	1.98	1.85
China	150.1	4.24	1.95
Korea	351	5.75	–
Japan	387.3	5.63	3.1
Pakistan	53.1	2.56	1.65
World average	78.5	2.86	1.92

Need for the Application of Fertilisers

Deficiency of any one or more of the nutrients in the soil impairs the growth and development of the plant. Ultimately the yield of the crop plant is affected. The plants develop characteristic symptoms due to the deficiency of nutrients. These are called deficiency symptoms or "Hunger Signs" of crops. Amongst the macroelements, Nitrogen (N), Phosphorus (P) and Potassium (K) are required in much larger amounts for plants. Referred to as NPK, these are also called the primary elements.

Fertilisers.– Fertilisers are generally grouped as–

1. Nitrogenous fertilisers

2. Phosphate fertilisers

3. Potassium fertilisers.

1. **Nitrogenous fertilisers.—** Ammonium sulphate, ammonium nitrate and urea.

2. **Phosphate fertilisers.—** Superphosphate, bone meal, rock phosphate.

3. **Potassium fertilisers.** Muriate of potash (KCl), sulphate of potash (K_2SO_4).

The NPK fertilisers are also available as mixed fertilisers. Special care should be taken while applying them to the nursery to avoid injury to the seedlings. Adequate soil moisture is essential following the fertiliser application.

Economic and Ecological Aspects of the Use of Fertilisers

Chemical fertilisers are expensive and their manufacture depends on the dwindling resources of energy such as petroleum and coal. Their production also releases pollution. Further, fertilisers applied to crop plants are lost in surface run-off and pollute soil and water resources.

BIO-FERTILISERS

Materials of biological origin which are commonly used to maintain and improve soil fertility are called *bio-fertilisers*. These can be discussed under the following headings :

1. Manures
2. Crop residues
3. Nitrogen fixation

Manures

Manures are organic materials added to soil to increase crop productivity. They supply all the elements required by the crop plants. The green manures also improve the physical condition of the soil by protective action against erosion and leaching. The manures are of three types :

1. **Farm yard manure. —** It is the most valuable organic matter commonly applied to the soil. It consists of a mixture of cattle dung and crop residues. The cattle dung is to be properly

stored in a pit. The pit is to be dug under the shade and the dung is kept moist. The surface is plastered with mud. The manure becomes ready after 4 - 5 months.

2. Compost. — This consists of cattle-shed wastes, refuse, farm weeds, rotted vegetables, groundnut husk and other substances. These are properly mixed and used after rottening.

3. Green manure. — A quick maturing crop is raised and ploughed into the field. Leguminous crops like Dhaincha, Cluster, Beans, Sawn-hemp, cowpea, Horsegram, Barseem are grown as green manure crops. Green manure supplies organic matter and additional nitrogen. It also provides a protective action against erosion and leaching. There is 30–50% increase in the crop yield by using green manure.

Table 47.2: **Plants commonly used as green manure**

	Common name		Botanical name
1.	Dhaincha	–	*Sesbania aculeata*
2.	Cluster bean	–	*Cyamopsis tetragonoloba*
3.	Lentil (Masur)	–	*Lens esculenta*
4.	Senj	–	*Melilotus parviflora*
5.	Barseem	–	*Trifolium alexandrinum*
6.	Horse-gram	–	*Macrotyloma uniflorum*
7.	Sunn-hemp	–	*Crotolaria juncea*
8.	Cowpea	–	*Vigna sinensis*

NITROGEN FIXATION

Nitrogen fixation may be defined as the phenomenon of the conversion of free nitrogen of the atmosphere into nitrogenous salts which are readily absorbed by the plants.

Nitrogen is an inert gas. It cannot be used directly by the plants. It has to be fixed with C, H, N, O to form compounds. Higher plants utilise nitrogen in the oxidised form such as nitrate (NO_3^-) and nitrite (NO_2^-), and also in the reduced form (NH_4^+) which is made available to plants by the nitrogen fixers.

Certain symbiotic bacteria like *Rhizobium* and *Bacillus radicicola* live in the nodules of the roots of leguminous plants. These bacteria on entering the roots through the root hairs from the soil form root nodules in leguminous plants like beans, gram, groundnut and soyabean. A root nodule in section

appears pinkish due to the presence of a pigment, *leghemoglobin*. This pigment is related to *hemoglobin*, the red pigment of human blood. Like hemoglobin, leghemoglobin also absorbs oxygen. Enzyme *nitrogenase* catalyses the fixation of nitrogen under anaerobic conditions.

Certain free living microorganisms like cynobacteria and photosynthetic bacteria also fix nitrogen. Some cyanobacteria live in symbiotic association with lichens, *Anthoceros* (a liverwort), fronds of *Azolla* (a water fern) and roots of *Cycas*.

Process of Biological Fixation of Nitrogen

In the presence of an enzyme *Nitrogenase*, the dinitrogen molecule is progressively reduced by the addition of pairs of hydrogen atoms.. In the end the three bonds between the two nitrogen atoms are cleaved and ammonia is formed.

The process requires strong reducing agent and energy (ATP) to transfer hydrogen atoms to dinitrogen. Ammonia formed in the process of biological nitrogen fixation is used for the synthesis of aminoacids. These are transported to other parts of the plant where they are needed.

(*i*) Free living microorganisms (**nitrogen fixers**) convert nitrogen into ammonia (NH_3) or ammmonium ions present in the soil. But ammonia is toxic to plants whereas ammonium ions can be taken up safely by the plants. But flowering plants are more adapted to absorb nitrate (NO_3^-) than ammonium ions (NH_4^+) from the soil as a source of nitrogen. Nitrogen fixing bacteria like *Nitrosomonas* and *Nitrosococcus* convert ammonia to nitrite (NO_2^-) ions and then *Nitrobacter* oxidises nitrite to nitrate. This process cf converting ammonia into nitrate is called *nitrification*. These bacteria are *chemoautotrophs* since they derive energy from oxidation of ammonia or nitrates for the synthesis of their own food.

(*ii*) *Azolla – Anabaena symbiosis – Azolla* is a fast growing and floating fern. In the cavities of its leaves is found a cyanobacterium, *Anabaena azollae*. This bacteria fixes free nitrogen of the air and extrates nitrogenous compounds into the cavities of leaves. Such leaves are an excellent bio-fertiliser. The use of *Azolla* leaves has resulted over 50% higher yields.

In certain South-East Asian countries, farmers stock *Azolla* along with pig manure, straw, ash etc. at the time of transplantation of seedlings. *Azolla* plants grow profusely between the rice plants. In the summer months, *Azolla decays and releases the nitrogen fixed by its algal partner.*

(*iii*) **Free living bacteria** – Free living bacteria such as *Azotobacter* and *Bacillus polymyxa* fix free nitrogen of the air. This nitrogen is utilised by the crops like cereals, millets, fruits and vegetables. With cotton, rice, maize and jowar plants, *Azotobacter* results in increased yield and there is a saving of nitrogenous fertiliser upto 10–25 kg/hectare.

(*iv*) **Cyanobacteria** – *Anabaena, Nostoc* and *Aulosira* derive the energy for nitrogen fixation through photosynthesis. These organisms have been used as bio-fertilisers at the Indian Agriculture Research Institute. It is estimated that upto 20–30 kg/hectare of nitrogen is fixed by these cyanobacteria.

The use of cyanobacteria involves low cost based on simple technology. It has a potential to supply 7–8 lac tonnes of nitrogen equivalent to 15–17 lac tonnes of urea. This is enough to meet the needs of the entire crop in our country.

(*v*) **Azospirillum** – Scientists at the I.A.R.I. New Delhi, have isolated *Azospirillum* from the roots of grasses, rice, sorghum and maize. Simple seed inoculation with this bacterium increases the dry weight of cereals. When mixed with a chemical fertiliser, it gives high yields.

(*vi*) **Mycorrhiza** – These represent a symbiotic association of certain fungi with the roots of certain seed bearings plants. These are of two types – *ectomycorrhiza* and *endomycorrhiza.*

(*a*) **Ectomycorrhiza** is the association in which there is a well developed mycelium forming a mantle on the outside of the root. This increases the surface of interface between plant roots and soil. Due to mycorrhizae, water and nutrient uptake of plant increases. This results in greater plant vigour, growth and yield. Ectomicorrhizae are found in the roots of oak, pine, peach and eucalyptus. They absorb and store nitrogen, calcium, potassium and phosphorus in the fungal mantle.

(*b*) **Endomycorrhiza** is the form of association in which the fungus lives between and within the cells of the cortex. It is found in many herbaceous species like orchids and certain woody plants. In one of the endomycorrhizae, fungus lives between the cells of the cortex and forms temporary hyphal projections that penetrate the cortical cells. These are called *vesicular arbuscular mycorrhizae* or VAM. VAM are important in the phosphate nutrition of plants. Many grasses and crop plants develop symbiotic association with VAM. Due to increasing cost of irrigation and synthetic fertilisers, this relationship is gaining importance.

Mycorrhizal association converts a marginal land into a fertile land and, reduces the dependency on irrigation and fertilisers.

QUESTIONS

1. Why are bio-fertilisers preferred to chemical fertiliser?
2. What is the difference between a green manure or a bio-fertiliser?
3. What is compost and how it differs from green manure?
4. Give one example each of the following :–
   (*a*) Green manure   (*b*) Bio-fertiliser
   (*c*) Symbiotic bacteria.
5. "Legumes fertilise the soil but cereals do not" .– Discuss.
6. Discuss VAM.
7. Match the items in column I with those in column II:

Column I	Column II
(*a*) Maize	(*i*) Mycorrhiza
(*b*) Pea	(*ii*) Anabaena
(*c*) Pine	(*iii*) Azospirillum
(*d*) Azolla	(*iv*) Rhizobium
	(*v*) Phoromone

8. What do you understand by nitrogen fixation?

CHAPTER 48

Crops Today, Current Concerns and Genetic Conservation

INTRODUCTION

Because of ever increasing need of growing human population, scientists are trying to improve naturally occurring crops plants varieties so as to produce high yielding and disease resistant varieties.

Genetic material contained within the reproductive cells is called *germplasm*. It is essential that the original germplasm of wildly occurring varieties be retained and conserved. The germplasm is collected from the areas where agriculture practices are primitive and hybridization has not taken place in their wild varieties. Some of these areas are Peru, Chile, Bolivia, Middle East, South-East Asia, Ethiopia and the Mediterranean.

Barely, coffee and sorghum originated in Ethiopia. The native place of beets, cabbage lettuce, oats, olives and asparagus is the land bordering the Mediterranean sea. Asia Minor and Afghanistan are the native places of rye, almonds, apricots, apples, lentils, apples, peas, pomegranates and pistacitrios. Wheat came from South-West Asia and South-East Asia is the native place of rice, banana, oranges, black pepper, brinjal, sugarcane and mango. From China came tea, onion, soyabean and persimmon.

Sunflower came from USA and pineapple and rubber from Brazil. Mexico and Central America are the native places of Maize. Peruvion Andes is the original home of potatoes and tomatoes.

Early man carried plants from one place to another. Rivers, migratory birds, aircrafts and man himself helps plants to migrate from one country to another country. In the beginning plants were introduced by explorers and adventurers, but the recent introductions have been made by scientists through international agencies based on strict plant quarantine requirements.

Agricultural development throughout the world is based on the introduction of useful plants to new areas. The major crops originating in the New World and the old world and the places of origin of some important crops and the areas of today's production are given in the tables below :

Table 48.1: New World and Old World Crops before Fifteenth Century

New World	Old World
1. Avocado	1. Almond
2. Cashew	2. Apple
3. Coca	3. Beet
4. Cocoa	4. Brinjal
5. Cotton	5. Barley
6. Custard apple	6. Black pepper
7. Gauva	7. Banana
8. Kidney Bean	8. Coconut
9. Lima bean	9. Cabbage
10. Maize	10. Carroot
11. Potato	11. Cucumber
12. Tapioca	12. Cardamom
13. Pumpkin	13. Coriander
14. Papaya	14. Coffee
15. Red pepper	15. Cotton
16. Squash	16. Date
17. Quinoa	17. Fig
18. Sunflower	18. Garlic
19. Pineapple	19. Grapes
20. Sapota	20. Jute
21. Tomato	21. Jackfruit
	22. Lentil
	23. Lemon
	24. Mango
	25. Mustard
	26. Olive
	27. Onion
	28. Orange
	29. Poppy
	30. Pomegranate
	31. Pear
	32. Peach
	33. Pea
	34. Rye
	35. Rice
	36. Radish
	37. Sorghum
	38. Soyabean
	39. Spinach
	40. Sugarcane
	41. Tea
	42. Watesmelon
	43. Wheat

	Crops	Centres of Production	Centres of origin
1.	Cacao	Africa	Brazil
2.	Coffee	Brazil and Central America	Ethiopia
3.	Groundnut	India	Peru, Brazil
4.	Maize	Midwest U.S.A.	Tropical America
5.	Monterey pine	Australia	California
6.	Oilpalm	Malaysia	Tropical Africa
7.	Pineapple	Hawaii	Brazil
8.	Potato	Easten Europe	Peru
9.	Rubber	Malaysia, Indonesia	Brazil
10.	Wheat	North-central, North America	Central Asia

GENE POOL AND GENETIC CONSERVATION

What Is Gene Pool

The sum total of genes of all the individuals of a population is known as *gene pool*. Gene pool may appear constant but it keeps changing by the hereditary changes in the genes of individuals.

Genetic erosion is the loss of genes from a gene pool caused by following factors :

(*i*)   deforestation,

(*ii*)   urban expansion,

(*iii*)   shifting cultivation,

(*iv*)   damage to coastal and mountain ecosystems, and

(*v*)   adoption of genetically uniform modern varieties of crops.

Because of man's activities and encroachment, the natural environment is changing and so the naturally occurring species are also dwindling. Many genes from wild population have been found to be useful. It is also essential that the original germplasm of wildly occurring varieties be retained and conserved. Scientists and Geneticists are making efforts to conserve the beneficial genes and transfer them to cultivated plants. There are four basic ways to conserve plant genetic resources:

1. To maintain the genetic resources where they are in wild places like forests and nature preserves them.

2. To hold the genetic resources in botanical gardens.

3. To feed them in the agricultural and horticultural trade so that people may cultivate them.

4. To preserve them in the form of seeds, or some other suitable material.

In its original form plant diversity can be maintained in Biosphere Reserves, National Parks and Wildlife Sanctuaries. Green plants directly or indirectly provide nutrition to all animals. Thus the conservation of habitats where gene pools of wild species occur within their natural communities is essential. Deforestation of about 11 million hectares of tropical forests every year has created serious implications to the *in situ* preservation of genetic variability. It has also endangered the quality of life of millions of forest dwellers and tribals living in harmony with nature. Conservation of wild plants in their national habitat has following advantages:

(*i*)   protects plants from the danger of extinction,

(*ii*)   plants supply materials to restore degraded lands, and

(*iii*)   a source for genetic improvement of crop plants.

Importance of Wild Species Germplasm

The crop plants receive human protection against pests and diseases and predators. Additionally these plants need proper ploughing, irrigation and fertilisation. In contrast, wild plants have to thrive on their own. Further, they have to manage on soils that are unfavourable to them. These plants have developed various adaptations.

Thus the wild plants with above mentioned wild traits are valuable to plant breeders. The germplasm of such plants is tapped for resistance to diseases, pests and extremes of environment.

Following examples are cited for the contribution of wild plants for the improvement of cultivated crops:--

1. Potato. – The common cultivated potato *Solanum tuberosum* has greatly benefitted from its wild relatives. *S. acaule* has provided resistance to potato virus X and potato leaf roll virus. *S. stoloniferum* has donated a gene that gives resistance to potato virus Y. The resistance to *Phylopthora infestans*, the fungus that caused the great potato famine of Ireland in 1845 comes from *S. demissum*. *S. spegazzini* has given resistance to five races of cyst nematode, *Globobera*, and to the fungus *Fusarium coeruleum*. *S. vernei* has also donated resistance to *Globodera*.

2. Sugarcane. *S. officinarum* has obtained resistance to red rot disease and adverse environment from Kans, the wild *Saccharum spontaneum*. Breeding work done in Coimbatore in 1920's has helped in developing Co canes. This has helped in establishing sugar industry in India and other 26 countries in the world.

Maintaining Genetic Diversity By Retaining Old Germplasm.

1. **By farmers** – Farmers maintain genetic diversity of crops and retain germplasm of wild species by collecting and storing seeds or by collecting tubers, rhizomes, and bulbs etc. for raising next generation. In some cases fresh cuttings are planted immediately after the harvest.

2. **By Gardeners** – Gardeners cultivate rare or selected varieties of garden plants, fruit trees and decorative plants. It is because of garden lovers that Ginko tree has become so common.

    Efforts at individual level by nature lovers has helped in conserving not only the rare varieties of plant but of animals also and have saved them from extinction.

3. **At Botanical Gardens** – Collection of seeds or pods of cultivated and wild varieties of plants and storing them in botanical gardens and gene banks is another method of conserving the germplasm. Such offsite collections of agriculturally, geographically or ecologically diverse plants can be used by scientists in crop improvement.

Botanical gardens and arboretums (or arbor eta) form primary repository for wild plants.

1. Gene Banks

The institution where valuable plant material likely to be lost in the wild state or in cultivation is preserved in a viable condition is called **Gene Bank**. A gene bank conserves a stock of both seeds and vegetative material.

In a plant museum relics of the past plants are simply preserved or displayed. But in a gene bank the germplasm is stored. The stored germplasm has two advantages –

(*i*) it safeguards the species threatened with loss or extinction,

(*ii*) it is utilised the world over by plant breeders to develop new and better yielding varieties resistant to stresses, pests and diseases.

The most convenient method of maintaining plant germplasm is by storing seeds.

Storing seeds .– In seeds living material remains in a metabolically suspended state. Seeds can be stored for long periods by avoiding conditions favourable for respiration and enzymatic action. This is achieved by controlling the availability of oxygen, moisture and temperature. Seeds when dried and kept at low temperatures last for longer periods. Seeds become damaged when dried below 5°C. The lowest temperature that seeds can tolerate is –10°C to –20°C.

Seeds which are viable at low moisture and temperature are called **orthodox seeds.** Many staple food crops like cereals and legumes have orthodox seeds. Some of them when properly dried can be cooled as low as –196°C. Seeds that are killed by drying and freezing temperature are termed **recalcitrant seeds.** Jack-fruit, tea, rubber, palms, coconut, litchi, cocoa and tropical fruit plants and timber species bear recalcitrant seeds.

Recalcitrant seeds help in conserving the crops *in situ.* These seeds can also be treated with fungicides. For short periods they can be kept moist with access to oxygen.

Tissue Culture and Germplasm Storage

Germplasm is stored by tissue culture methods in following ways:

(*i*) for maintaining a specific genetic type (clone),

(*ii*) for highly variable seed progeny,

(*iii*) for plants with recalcitrant seeds, and

(*iv*) when seeds are altogether absent as in banana, sugarcane and arvi.

Tissue culture system to be employed for the storage of germplasm should be able to retrieve the material at the end of its storage period and its genetic ability.

Advantages of Tissue Culture Method of Preserving Germplasm

1. International exchange of germplasm is preferred in terms of shoot tip cultures because they are more stable, easier to regenerate into whole plants and able to produce virus-free clonal plants.

2. Elimination of virus infection by shoot-tip culture has made it important for germplasm exchange. For this reason, cassava, banana and potato cultivars are exchanged the world over.

3. A large number of genotypes can be stored in a relatively small area, in culture vessels at a fraction of the cost of annually growing large living collections in the field.

4. With the help of tissue culture method, endangered plants can be multiplied, with the possibility of reintroducing them into their original habitats.

3. Cryopreservation

Preservation of germplasm at low temperatures of around – 196°C is called *cryopreservation*. At such low temperatures, the cell division stops, biological activities cease and genetic change does not occur.

In addition to crop plants, freeze preservation is also employed for cultured animal cells, spermatozoa, ovarian and embryonic tissue and also whole animal embryos. It is also used for livestock breeding programmes. Thus a wide range of microbes, algae, insects and other organisms including animal and human cells are needed to be stored for any possible future use. This also forms the basis for biotechnological activities.

Global Efforts In Harnessing Crop Germplasm

Wheat and rice are two staple food crops of the world. But low yields, lodging, susceptibility to diseases, pests and extremes of environmental conditions were responsible for crop losses and low yields.

New high yielding varieties of rice and wheat were obtained by the introduction of dwarfing genes, Dee-geo-woo-gen in rice from Taiwan and Norin 10 from Japan in wheat. NORMAN E. BORLAUG developed new Mexican wheat varieties which ended hunger in Mexico and several countries of Asia. For this, he was awarded **Nobel Prize** for peace in 1970. The dwarf Mexican wheats Sonora-64 and Lerma rojo–64 were introduced in our country in 1963. Their further selection and modification by Dr. M.S. SWAMINATHAN and other Indian leading agriculturalists was responsible for 'Green Revolution' in India. This made India self-sufficient in food grains for the first time. This opened a new vista for achieving high yield varieties of several crops.

Green Revolution shows the importance of International Cooperation in breeding programmes and germplasm exchange in the developing countries. International Rice Research Institute (IRRI) at Manila, Phillippines developed a most widely planted rice variety. This shows the importance of international cooperation in breeding, germplasm conservation and exchange.

A Case Study of I.R. 36

In early 1970, when epidemic caused by 'grassy stunt virus' destroyed over 1,60,000 hectares rice in Asia, wild variety of rice *Oryza nivara* from central India was found to be resistant. Plant breeders from Punjab Agricultural University under Dr. G.S. Khush developed a cultivar variety IR 36 by interbreeding *Oryza nivara* and 13 other rice varieties from six other countries. IR 36 is the most widely grown variety in the world. It occupies over 10 million hectares and is responsible for an additional 5 million tonnes of rice each year on a global scale. It is early maturing and takes 107–110 days for harvest. It resists most of the rice pests and diseases.

New Crops

Of the 350,000 species known, only a few hundred have been found in everyday use. Of these 30 major crops are given in the table given on next page.

Table 48.3: Annual world production in millions of metric tons of major crops.

S. No.	Crop	Production
1.	Wheat	450
2.	Rice	395
3.	Corn	400
4.	Potatoes	295
5.	Barley	180
6.	Cassavas	115
7.	Soyabeans	105
8.	Grapes	80
9.	Oats	65
10.	Sorghum	60
11.	Sugarcane	55
12.	Oranges	50
13.	Millets	50
14.	Bananas	45
15.	Sweet potatoes	155
16.	Tomatoes	45
17.	Sugarbeets	35
18.	Rye	30
19.	Apples	30
20.	Coconuts	30
21.	Cotton seed oil	30
22.	Peanuts	25
23.	Yams	25
24.	Watermelons	20
25.	Cabbages	15
26.	Onions	15
27.	Beans	10
28.	Peas	10
29.	Sunflower seeds	10
30.	Mangoes	10

Underutilized Crops

To meet the increasing demands of people, scientists are searching for under utilised and under-exploited plants. Some of such plants are as under—

1. Winged Bean - The winged bean, *Psopho-carpus tetragonolobus*, is a herbaceous, nitrogen-fixing legume found in tropical regions of Asia. It is a vine reaching a length upto 3m. Its pods are long and four-winged.

Its tuberous roots, leaves, pods and seeds are rich in protein. These are edibles and used by humans and cattle.

Pods, leaves and shoots are eaten as vegetables. Ripe seeds are roasted and eaten, and unripe seeds are used in soup. The nutritive value of ripe seeds is close to soybean *i.e.* 34% protein and 18% oil.

2. Jojoba — The jojoba, *Simmondsia chinensis*, occurs in the Mexican deserts. The plant is dioecious. Female plants start fruiting when 3 or 4 years old, reaching maximum yield after 10 years.

The seeds contain about 50% by weight of a liquid wax. This is of the same quality as sperm whale oil used as a high-performance lubricant.

Jojoba is a drought resistant desert shrub. It can thrive under poor soil and low moisture conditions. Its cultivation in arid regions of the world would help in the uplift of economic condition of the poor.

3. Guayules (*Parthenium argentatum*). — It is a perennial rubber-bearing shrub which grows wildly in the deserts of Mexico and South Western United States. It grows on marginal lands and poor desert soils. It is a shrub with a potential source of natural rubber. On dry weight basis, it gives upto 12% rubber while improved varieties can yield upto 20% rubber.

4. Laucaena (*Leucaena leucocaphala*) Commonly known as subabul, it is a fast growing leguminous tree occurring in central America. It can grow on poor, worn-out marginal lands.

The tree has diverse uses. These include revegetating deforested tropical lands, providing wind breaks, firebreaks, shade and ornamentation. It produces palatable and nutritious forage for the cattle, buffaloes and goats. Food is used for fuel and charcoal. Its wood is also suited for manufacturing paper, pulp and rayon. The plant fixes nitrogen and the foliage is a good source of green manure.

Other Underutilised Plants

1. Oils. – Many of the edible vegetable oils are being diverted for industrial use. Following are the potential crops to meet ever increasing oil requirements both for industrial and edible purposes:

1. Buffalo gourd (*Cucurbita foetidissima*)
2. Bitter colocynth (*Citrullus colocynthis*)
3. Neem (*Azadirachta indica*)
4. Sal (*Shorea robusta*)
5. Karanj (*Pongamia prinnata*)
6. Brihathpilu (*Salvadora persica*)
7. Mahua (*Madhuca indica*)

2. Drugs and medicinal plants — A large number of plants are cultivated for specific drugs. A large number of the plants are collected in wild form. Some of them have endangered for

extinction. Scientists are making continuous search for new medicinal plants. A new approach in medicine is to establish the scientific basis of certain drugs used in traditional systems. These medicines are for combating recalcitrant diseases such as hypertension, Hepatitis B infection, obesity and high chlosterol in blood.

3. Beverages. — Besides coffee, tea and cocoa, there are a few less known tropical sources of beverage plants. These are as follows :

1. **Mate or paraguay tea** (leaves of *Ilex paraguriensis*)
2. **Guarana** (seeds of *Paullina cupana*)
3. **Cola** (Powdered seeds of *Cola nitida*)
4. **Khat** (a decoction from the leaves of *Catha edrilis*).
4. **Forage** – To support a large population of poultry and livestock, and also to increase animal production, new sources of the plants have to be utilised as forage. Some of the important ones are given below:

1. *Ailanthus excelsa* (maharuk)	– A fast growing tree. Its branches are topped for feeding goats.
2. *Albizia lebbek* (siris) *A. procera*	– Young foliage contain 20% protein and are fed to livestock.
3. *Acacia nilotica* (babul, kikar)	– Leaves and pods are used for feeding goats and sheep. Leaves and twigs of *A. senegal* provide excellent fodder.
4. *Anogeissus latifolia* (Dhawa)	– Foliage is used as food
5. *Ficus religiosa* (Peepal)	– Leaves are lopped for elephants and cattle fodder.
6. *F.benghalensis* (Barh)	
7. *Gmelina arborea* (Gumhar)	– Foliage, seedlings and fruit are used to feed livestock.
8. *Moringa oleifera* (Drumstick) and (Sanjna)	– A fast growing tree which is lopped for foliage and tender fruits.
9. *Morus alba* (Shehtoot)	– Leaves are used as forage for goats, cattle and sheep.
10. *Azadirachta india* (Neem)	– Lopped to feed goats and cattle in the semi-arid regions of India.
11. *Zizyphus mauritiana* (Ber)	– Foliage used for cattle, camels and goats
12. *Sesbania grandiflora* (Agati)	– Its fleshy, feathery leaves and long pods are eaten by cattle.
13. *Quercus semecarpifolia* (Maru)	– Tree is lopped and fed to livestock.

QUESTIONS

1. Discuss the need of genetic conservation.
2. Define gene pool and gentic erosim. Name various steps necessary for contralling genetic erosion.
3. Discuss importance of wild species gemplasm.
4. What were the reasons that the earliest human races settled in the great river valleys?
5. Justify the statement wild species are more sturdy and better adopted than the domesticated varieties.
6. Define the following terms :
   (i) Genetic conservation
   (iii) Gene pool
   (v) Recalcitoant
   (ii) Gene bank
   (iv) Generic load
   (vi) Cryopreservation
7. Differentiate between recalcitrant and orthodox seeds. Which of the two can be stored longer?
8. Give two examples each of the following:
   (i) Orthodox seeds
   (iii) New Crops
   (ii) Recalcitrant seeds
   (iv) Underutilized crops
9. Name two underutilized corp plants from which following can be obtained :
   (i) Oils
   (iii) Beveragaes.
   (ii) Drugs and medicine

□ □

Application of Tissue Culture and Genetic Engineering in Crops.

TISSUE CULTURE

The simple undifferentiated tissue or the primary meristems of stem and root tips show an organized growth in basic culture medium. But, the fully differentiated tissues such as pith, secondary pholem, mesophyll and endosperm etc. in basic medium grow into an unorganized and undifferentiated mass of tissues, called *callus*. GAUHERST, NOBECOURT and WHITE (1939) succeeded in growing callus *in vitro* from isolated plant parts called *explants*. By altering composition of basic medium or adding certain hormones, it is now possible to obtain callus culture from most plant tissues, including those that would have never divided in nature.

Depending on the nature of plant tissue cultured, the callus may remain as an undifferentiated and unorganized mass or may differentiate into shoots, roots or embryo-like structures (the embryoids). However, the use of different growth hormones like auxins and cytokinins in appropriate proportion in the culture medium induces differentiation of different plant parts in callus (*organogenesis*).

Skoog and Miller Experiment on Tobacco Pith Tissue

SKOOG and MILLER demonstrated that the presence of different growth regulators in different concentrations influences the differentiation of unorganized mass of cells into roots and shoots (*organogenesis*).

(1) Excised tobacco pith tissues were grown on basal medium (*i.e.*, without growth regulating hormones). The cultured tissue showed poor growth (Fig. A).

(2) The same tissue was grown in a culture medium containing 0.2 mg. of kinetin per litre. It formed a vigorously growing callus (Fig. B).

(3) A portion of this callus was transferred to culture medium containing 0.2 mg. litre of kinetin and 3 mg. litre of indole acetic acid, the callus showed formation of roots

(Fig. C).

(4) A portion of callus from B was transferred to culture medium containing 1 mg/litre of kinetin and 0.3 mg/litre of indole acetic acid. The callus showed formation of shoots (no roots) (Fig. D).
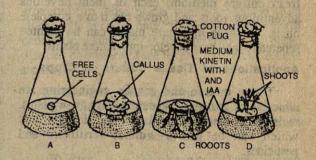
Fig. 49.1 Skoog and Miller's experiment to demonstrate the effect of growth regulators (auxins and cytokinin) on growth and differentiation in the culture of tobacco pith tissue

A – *In basal culture medium without growth regulator.*

B – *In culture medium with 0.2 mg. of kinetin in one litre of medium.*

C – *In culture medium with 3 mg. of IAA (auxin) and 0.2 mg. of kinetin (cytokinin) in one litre of medium.*

D – *In culture medium with 1 mg. kinetin and 0.3 mg. of IAA per litre of medium.*

The process of tissue culture involves separation of cells, tissues or organs of a plant and then growing them on suitable nutrient medium under specific conditions.

Todate, single cell culture of carrot, tobacco, Cuscuta and Asparagus have been obtained successfully. Besides this, GUHA and MAHESHWARI (1966) have succeeded in anther culture in *Datura* and now pollen embryos of wheat, barely, rice, tomato and Asparagus have been cultured. NITSCH

and her associates in France have grown anthers on a purely synthetic medium.

The type of growth response in tissue cultures depends on the source of explants, composition of medium and conditions in growth room.

Whether the callus differentiates in the normal course or its differentiation is induced by growth regulators, a number of roots and shoot buds appear on the surface of callus. In the beginning, the shoots and roots do not have vascular connection. But later on, the developing roots and shoots of callus get connected by vascular tissue forming the complete miniature plants. However, if these shoot buds are excised from the callus and transferred to a fresh culture medium, each of them develops adventitious roots and grows out into a complete plant. If these miniature plants can be planted separately they may develop into mature plants.

Applications of Tissue Culture in Crops

Tissue culture and genetic engineering are aimed at the selection and cultivation of new plants, resistant to diseases, predators and drought, and which can be grown without fertilizers and pesticides.

There are following applications of tissue culture in crop improvement :

(i) Micropropagation

(ii) Production of disease-free plants

(iii) Androgenic haploids and their uses in breeding

(iv) Embryo rescue for successful hybridization

(v) Induction and selection of mutants

(vi) Somaclonal variation

(vii) Protoplast technology

1. **Micropropagation .—** Micropropogation is rapid vegetative multiplication of plant material for agriculture, horticulture and forestry. The process is very fast and highly productive. Micropropagation is of great advantage because –

(i) Tissue culture provides rapid multiplication. Under favourable conditions, a small plant, bearing five or six leaves is produced within a few weeks which under normal conditions may need several months.

(ii) By tissue culture techniques, large number of offsprings or plantlets can be obtained every year. For example, a progeny of 50,000 raspberry plants can be obtained from its meristem culture, whereas only 50 plants a year are formed with conventional cutting techniques.

(iii) The progeny of those plants can be obtained in millions, which multiply with difficulty by conventional methods.

(iv) Cloning can be done throughout the year in a very small space under controlled conditions.

(v) Offsprings can be obtained of sterile plants or of rare hybrids of extraordinary characters e.g. oil palm.

Micropropagation is achieved by following methods –

(A) **Multiple shootlet production** – Shoot tips are used for tissue culture and raising mini plants. Shoot tips in culture medium produce multiple buds and each bud grows into a shoot. By using rooting hormone, the shoot is induced to produce roots.

Micropropagation of potato, cardamom, raspberry, peach, almond, orchids, bananas, gerberas, chrysanthemums, begonias etc. is being successfully done on commercial level.

(B) **Somatic embryogenesis** – The embryos developed from a single somatic cell by tissue culture are known as *somatic embroys* or *embryoids.*

In carrots, celery and alfalfa the somatic embryos can be produced in thousands in a small volume of nutrient medium.

2. **Production of disease-free plants .—** In plants which are propagated vegetatively by roots, bulb, tuber or rhizome etc., the pathogens (viruses etc.) are transmitted to the offsprings through these propagules. But if plants are raised by tissue culture from the shoot tips of such infected plants, they are free of pathogens.

Healthy plants of potato, sweet potato, cassava, sugar cane, strawberry, carnation, Delhia, and many

more ornamental plants are grown by tissue culture method.

3. Androgenic haploids .— By anther culture androgenic *haploid embroys* or plantlets are obtained from the microspores or pollens. GUHA and MAHESHWARI (1966) produced androgenic haploid plants by anther culture of *Datura innoxia*. Now pollen embroys of wheat, barley, rice, tomato, other vegetable, fodder species and ornamental plants (*Asparagus*) and many other plants (about 250 plants) have been cultured.

The development of pollen into a haploid sporophyte (embryo) in culture medium is known as *male parthenogenesis*. If pollen grains are treated with colchicine before culture, *homozygous diploid* embryoids are formed (colchicine stops the cell division after chromosome separation and leads to chromosome doubling).

Significance of Haploid Plants (*i*) In haploid plants mutations—spontaneous or induced can express themselves and can be easily detected because haploids have only single set of genes. (In diploids a mutation is not easily detectable because of being heterozygous). (*ii*) Homozygous diploids can be obtained in a single generation by treating a haploid cell in culture medium with colchicine. (*iii*) When used on a large scale in hybrids, it combines the advantages of recombination, segregation and fixation.

In China haploids have been used to develop new varieties and strains of rice, wheat, maize and rubber etc.

4. Embryo rescue .— Interspecific hybrids are often sterile because of embryo mortality and seed collapse. In such cases, the hybrid embryo is excised from the female parent in early stage and is cultured on culture medium.

The interspecific hybrids of common bean (*Phaseolus vulgaris*) and wild bean (*P. angustissimus*) and of cultivated tomato and wild variety, *Lycopersicon peruvianum* have been developed by this method. These interspecific hybrids are either disease resistants or have improved nutrients or are resistant to pest.

5. Induction and selection mutants . Cells can be grown in suspension cultures by using liquid culture medium. The cultures can be exposed to continuous shaking by metabolic shaker. As a result the culture consists of isolated colonies. The isolated individual cells can be transferred to separate culture plates where clones of cells are grown. By adding chemical mutagens into the medium for various traits. When herbicides or toxins are added to the culture medium, the colonies or clones of cells that are resistant survive and others are perished. The plants can be raised from these tolerant cells for agriculture purposes. Thus by tissue culture technique mutations can be introduced in the cultures and resistant mutants can be selected to produce resistant varieties.

6. Somaclonal variations .— Somaclonal variations are differences in those plants that are raised from the callus by tissue culture. These arise only in those plants which are raised from clonal cells of callus only. If these variations are of economic value *i.e.* induce tolerance to pests, diseases or stresses or are helpful to overcome male sterility.

Somaclonal variants are known in
(*i*) *Wheat* — These are resistant to rust and have tolerance to high temperature.

(*ii*) *Rice* — These are resistant to Tungro virus and leaf hoppers

(*iii*) *Potato* — Somaclonal varients have high protein content.

(*iv*) *Tomato* — These have increased shelf life.

7. Protoplast culture .— Protoplasts are the naked plant cells whose cell wall is dissolved by enzymes *cellulase* and *pectinase*. Protoplasts can be isolated from leaves, stems, callus, suspension cultures and from pollen grains. These can be grown on Agar containing nutrients.

Genetic manipulation and somatic cell fusion in plant cells is not possible because of thick cellulosic wall. The plant cells are also held together by middle lamella. Therefore, preparation of protoplast is an essential step in tissue culture.

Protoplasts are utilized for the following purposes :

(*i*) For obtaining clones or protoclones.

(*ii*) The clones derived from leaf cell protoplasts are found to vary because of

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genetic modifications in somatic cells. In the field of agronomy, this has important bearing because it provides opportunity to select cell populations or clones that would give rise to plants with particular useful character.

(iii) **Protoplast fusion** – The protoplasts from different varieties or species can be made to fuse with the help of certain compounds such as **PEG**–polyethylene glycol or by *electrofusion* . This provides a chance for an extended variety of hybrid plants between nonrelated species and genera. Hybrids of wheat and rye, and turnip and cabbage, between species of *Brassica, Nictotiana, Petunia* and *Solanum* have been produced by protoplast fusion. In 1978, tomato and potato protoplasts were fused. The resulting hybrid is called *pomato*. It is of great scientific interest and agronomic importance.

QUESTIONS

1 . Discuss importance of tissue culture in the improvement of crop.
2 . Discribe various steps in preparing tissue culture of banana plant.
3 . How tissue culture can enhance production of trees and help in forestry and agronomy?
4 . Define the following terms :

    (*i*) Embryo   (*ii*) Embryoid

    (*iii*) Micropropagation   (*iv*) Androgenic haplod

    (*v*) Somaclonal variation

5 . Name some somaclonal variants of grain plants
6 . Discuss the significance of rearing androgenic haploids
7 . What is a protoplast ? Describe the mechanism of protoplast culture
8 . What great discovery helped in achieving protoplast fusion ?
9 . Define a clone ? What is the difference between somaclonal variants and monoclonal cells ?

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CHAPTER 50

Domestication and Improvement of Animals

Domestication of animals and plants provided the foundation on which civilization could be built. Just when the domestication of animals began is not known ; it certainly began during the hunting and gathering phase of human civilisation. As humans realised the importance of domesticating animals for use as beasts of burden and as sources of milk, meat, leather and fur, methods of improvement through selective breeding were used.

One of the earliest animals to be domesticated was dog. Dogs are represented in Egyptian monuments as far back as 3400 B.C. and various breeds of dogs existed during the height of the roman civilization. The dog was teachable and through careful training, it could be trained to protect the herds and flocks. Because of their sharp sense of smell and sight, dogs are used to trace criminals, drug peddlers and prowlers.

The cattle (cows, buffaloes and goat) were domesticated during the New Stone Age in both Europe and Asia. These provide milk to be taken as such or in the form of butter, curd and ghee. A large number of animals are used as 'beast of burden'. Man has used horses, ox, camel, buffaloes and elephants for the transport either in cart or as such. Reindeers in Tundra, Yak in Tibet and Bison in America are used for transport. The earliest trace of the horse hitched to a chariot goes back to about 2000 B.C. in Greece, whereas the first Egyptian records of the domestication of horse date back to about 1600 B.C.

It seems probable that primitive man first used members of the family Bovidae (cow, ox, bull, buffalo, sheep and goat) as a source of food. Domestication perhaps began when these animals were used as draft animals, probably in the first steps of the tillage of the soil. As civilization developed, feed became more abundant, methods of caring for livestock improved, and the latent possibilities for rapid growth, fat storage, and milk production began to be realized under man's selection.

LIVESTOCK

The importance of livestock in the economy of our country is well understood. On the basis of the utility the livestock can be put into the following categories—

1. **Milk Giving Animals .**— Cows, buffaloes and goats provide us with milk which provide animal protein and serve as a perfect natural diet. Milk is also used in preparing curd, butter, ghee, cheese etc.

2. **Meat and Egg Giving Animals .**— A large number of animals such as sheep, goat, pigs, ducks and fowls provide us meat and eggs.

3. **Animals utilized as Motive Power .**— Buffaloes, horses, donkeys, bullocks, camels and elephants are used in transport and ploughing the fields. It is justified to call the bullocks as tractor of the farmers in our country. Cattle are also used to draw water from the wells for irrigation.

4. **Wool Giving Animals .**— Sheep are reared for obtaining wool from their hide.

5. **Miscellaneous Uses .**— The hides of cattle are used for making a variety of leather goods. Horns of animals and feathers of birds are used for making a variety of goods and articles of decoration. India is the largest exporter of hides and skin in the world. Dung is used for maintaining the soil fertility and also as fuel.

CATTLE POPULATION

Numerically, India possesses the largest cattle population in the world. According to latest information India has 241 million cattle and buffaloes. This is nearly 18.3 per cent of the total cattle and buffaloes population in the world.

Milk Production

The performance of Indian cattle, particularly of cows, is very poor. The average annual milk yield per cow has been estimated at 173 kg and that of a

buffalo is 491 kg. The total milk production in 1979-80 was estimated at 30.20 million tonnes and is estimated to be 51.00 million tonnes in 1989-90.

The average per capita daily milk consumption in our country is very low as compared to advanced countries as shown in the table below :

Table 50-1: *Average per capita milk consumption*

Country	Per capita milk consumption
India	130 g
UK	509 g
USA	623 g
New Zealand	637 g
Switzerland	741 g

Feeding of Cattle

There is a old saying that the best milk comes from contented cows. Unfortunately paucity of feed and fodder is responsible for low milk production in our country. In the absence of good meadows and pastures, the cattle remain in semi-starved condition. This is responsible for poor milk production in our country. Therefore, a good feed is essential to increase the yield of milk.

A balanced feed consists of appropriate nutrients like carbohydrates, proteins, fats, minerals, vitamins and water in appropriate quantities. Cattle feeds are divided into two categories (1) roughages and (2) concentrates.

1. **Roughages.** Roughages contain large quantities of fibre and include hay, fodder and silage. These are of the following types—

(i) *Leguminous dry fodder*—It includes the husk of gram and pea.

(ii) *Leguminous green fodder*—Barseem, lobia, peas, cluster beans and lucerne are the common examples.

(iii) *Nonleguminous dry jodder*—This includes the remains of nonleguminous crops left over after thrashing. These are wheat straw, rice straw, oat straw, dubhay, jowar hay and jowar straw.

(iv) *Nonleguminous green fodder*—Different types of nonleguminous green fodder is used in different parts of the country. Sudan grass, Napier grass, Guinea grass, Elephant grass, Jowar fodder, Maize fodder and Bajra fodder are some of the commonly used fodders.

2. **Concentrates.** The concentrates have relatively high percentage of nutrients but low percentage of fibres (roughages). The concentrates are added to the roughages in required quantities to get a good yield of milk. Minerals and vitamins are added to the feed of high yielders. These are of the following types:

(i) *Grains*—Maize, wheat, barley, jowar, bajra and gram are the common grains of cereals, millets and legumes which are fed to the cattle. These are highly palatable and rich in starch.

(ii) *Byproducts of grains*—Gram churi, wheat rice and oat bran are the common by products of grains. These are rich in vitamins, minerals and starch.

(iii) *Oil cakes*—These include cakes of mustard and groundnut.

3. **Water.** It is most essential for all the living beings. Animals may live without food for more than 100 days but may die without water within 5-10 days. The drinking water should be clean and free of germs.

Cattle-breeding

Several important breeds of cattle are found in India. They are characterised by their body build, colour, nature of horns and forehead. Some of them produce good bullocks while in some cases cows of the breed provide better yield of milk production. Good and improved milk breeds are found in the states of Haryana, Punjab, Rajasthan and Gujarat.

In our country bulls are selected for breeding on the basis of draught ability. Such bulls are allowed to graze with the cows for random breeding. The bulls found unsuitable for breeding are castrated when young. These become bullocks and are the main draught power in India.

For artificial insemination, semen of high quality bulls is collected. About 60 per cent cows are artificially inseminated in our country. This ensures good quality progeny and also economical as semen from a single bull can fertilise several thousand cows.

Majority of Indian cattle are on marginal inputs and are infertile and poor milk yielders. The use of pregnant mare serum, *gonadotropin*, has helped in augmenting fertility. Implantation of stilbesterol tablets has helped in inducing lactation in sterile and immature cows.

Indian cows are cross-bred with European breeds like Holstein, Brown swiss, Jersey, Red Dane and others to increase the milk yield.

Super Ovulation and Embryo Transplantation

A pedigreed bull and a high production cow are crossed to produce super milk cows. Super-ovulation is done by hormone injection. As a consequent of artificial insemination, 4-10 embryos are collected at a time. The embryos are their transplanted into carrier cows. It has become possible to transplant such embryos in goats, sheep and other livestock also. By deep freezing *i.e.* – 196°C, seven days old embryos can be preserved for several years. Homozygotic twins can be obtained by cutting down an embryo into two. High quality bulls are selected for embryo transplantation for genetic improvement.

Table 50.2: Breeds of Indian cattle and buffaloes

Cattle	Distribution
A. Milch Breeds	
1. Sahiwal	Punjab, Haryana & U.P
2. Deori	Andhra Pradesh & Tamilnadu
3. Gir	Gujarat & Rajasthan
4. Red Sindhi	Andhra Pradesh
B. General Utility Breeds	
1. Ongole	Andhra Pradesh
2. Haryana	Haryana, Punjab, Bihar, M.P.
3. Tharparkar	Andhra Pradesh and Gujarat
4. Kankrej	Gujarat
C. Draught Breeds	
1. Nageri	Delhi, Haryana, U.P.
2. Kangayam	South India
3. Malvi	Rajasthan, M.P.
4. Hallikar	Karnataka
D. Buffaloes	
1. Nili Ravi	Punjab, Haryana
2. Nagpuri	Central and South India
3. Mehsana	Gujarat
4. Surti	Rajasthan, Gujarat
5. Jaffarabadi	Gujarat
6. Bhadawari	U.P and M.P.
7. Murrah	Punjab, Haryana, U.P.

SHEEP AND GOAT

According to livestock census, India has more than 41 million sheep and more than 80 million goats.

Goats and Sheep Rearing .– In our country sheep are reared for wool, skin and meat, and goats provide meat, milk, hair and skin. *Mohair* from Angora goats, and *pashmina* from Kashmiri goats are greatly valued for the manufacture of superior dress fabrics and shawls. Droppings of sheep and goat is a valuable source of manure.

Feeding of Sheep and Goats .– Sheep feed on green tender grass, weeds and herbage. Goats feed on a variety of plants by browsing on the buds and foraging on a variety of plants. Minerals mixture, oil cakes, pulses, sesame, corn and jowar are also fed to keep these animals in good shape.

Sheep and Goat Raising .– In India, the maximum concentration of wool yielding sheep is in the arid regions of Rajasthan, Kutch, Saurashtra and North Gujarat. In south, the Deccan Plateau has the largest population of sheep. But, the majority of sheep in this area are hairy and yield very little wool. Superior-wooled types sheep are raised in Kashmir, Himachal Pradesh, hilly districts of Uttar Pradesh, Sikkim and Arunachal Pradesh. In our country, the people who rear sheep are called shepherds. They move from place to place along with sheep according to the changes in the seasons and availability of grazing.

The primary goal raising regions in our country are Andhra Pradesh, Bihar, Gujarat, Karnataka, M.P., Maharashtra, Orissa, Rajasthan, Tamilnadu, U.P. and West Bengal.

Sheep and Goat Breeding. Breeding should start at the age of 14-18 months (in case of females) and the male should be $2\frac{1}{2}$ years of age. For breeding it is essential to select ewes and ram or goats which are found must suitable for local conditions. There are different breeds for quality of wool and mutton or meat yield. Improvement in the quality and yield, of wool of local breeds of sheep is being achieved by cross-breeding with exotic breeds of sheep like Dorset, Horn, Suffolk and Merino (Spanish in origin and presently raised in Australia).

The various breeds of domestic goats have been derived from the wild goat (*Capra hircus*) of Baluchistan and Sind. Goats are reared in open sheds as they can withstand bad weather. They are called the *poor man's cow*.

Breed	Distribution	Use
1. Patanwadi	Gujarat	Wool for army hosiery
2. Marwari	Gujarat	Coarse wool
3. Nellore	Maharashtra	Mutton, no wool
4. Deccani	Karnataka	Mutton, no wool
5. Lohi	Punjab, Rajasthan	Good quality wool, milk
6. Rampur-Bushair	Uttar Pradesh, Himachal Pradesh	Brown coloured fleece superior cloth.
7. Nali	Haryana, Punjab Rajasthan	Superior carpet wool
8. Bhakarwal	Jammu & Kashmir	Under-coat used for high quality woollen shawls.

Some goat breeds

1. Marwari	Rajasthan
2. Berari	Maharashtra
3. Malabari	Kerala
4. Bengal	Bihar, Orissa
5. Gaddi	Himachal Pradesh
6. Kashmir Pashmina	Hills of Kashmir, Tibet, Himachal Pradesh
7. Jamunapuri	Uttar Pradesh, Madhya Pradesh
8. Beetal	Punjab

Diseases of Farm Animals

Farm animals suffer from various diseases. These diseases can be grouped in the following categories:

1. **Viral Diseases** – Anthrax and pox in cows, buffaloes, fowl, sheep and goats.

2. **Bacterial and Fungal diseases** – This includes tuberculosis of cattle, contagious bovine abortion, calf diphtheria, necrosis of feet and tail and foot rot of sheep.

3. **External parasites** – Lice live as external parasites on the body of cattle.

4. **Common ailments** – Common ailments of cattle are abscesses, fractures, bruises and wounds.

5. **Dermatitis** – It is of common occurrence in goat and sheep.

Control of Diseases

1. Spread of several diseases can be controlled by proper preventive and sanitary measures.

2. Incidence of Rinderpast, anthrax, pox, tuberculosis, bovine abortion, calf diphtheria and other contagious diseases can be considerably reduced by vaccination.

3. External parasites like lice can be controlled by applying dilute solution of insecticides like lindane.

4. Calf losses can be prevented by taking care of the new-born calf.

PIGS

In India, pig raising and pork production are in a primitive state. Pig rearing is almost entirely in the hands of poor people with little resources, who continue to follow old and primitive methods. The common village pig in India, is a scrub animal and has no definite characteristics. It is a slow grower and the pork is of poor quality. It is small-sized and produces small litters.

In India, the country pigs are mostly neglected. They do not get a fair chance to grow into economical animals for the industry. Recently commercial pig-breeding forms and pork-processing factories have been established.

Uses of Pig

1. Pig meat is called *pork*. It is inexpensive and is taken by the poor.

2. Hide of the pig is used as leather and its bristles for making brushes.

3. The fat obtained is used for soap manufacture.

4. Pig droppings are a good source of nitrogen, phosphorus and potassium for agriculture.

5. Ham, bacon and sausages are prepared from pig meat.

The important Indian breeds of pigs are given in the table on next page.

Domesticated indigenous Pigs	Distribution
1. Desi	Uttar Pradesh, Bihar, Punjab, Madhya Pradesh
2. Ghori	Manipur, Assam, Meghalaya, Arunachal Pradesh
Exotic Pigs	
3. Berkshire	UK (United Kingdom)
4. Large white Yorkshire	U K
5. Landrace	Switzerland and Denmark

Feeding of Pigs

Pigs feed on garbage, kitchen waste, vegetables and human excreta. Domestical indigenous pigs are fed on grass, straw and grains. They are also fed roots and tubers. Pork must be cooked well to avoid tape worm infections.

HORSES, DONKEYS AND MULES

Horses .– The horse is perhaps one of the earliest animals domesticated by man. As a class, horses, donkeys and mules are first cousins. They are single-toed animals with their toes enclosed in hoofs. At present there are 60 different domesticated breads of horses in the world.

Horses are intelligent and are known for their robust common sense. For thousands of years horses have been used to carry man on their back, pulled the carts and chariots both in peace and war. The horses are fast learner and loyal friends. They adopt themselves to all kinds of climates. They are used by the armed forces and police and are used for transport at high altitudes. They are used for riding, race and polo.

Breeds of Horses – The most important breeds of Indian horses are:

Name	Regions
1. Kathiawari	Rajasthan and Gujarat
2. Marwari	Rajasthan
3. Bhutia	Punjab and Bhutan
4. Manipuri	North-eastern –Mountains
5. Spiti	Himachal Pradesh
6. Zanshari	Ladakh.

Housing – Horses should be kept in hygenic and comfortable stables. Stables should be able to provide sufficient protection from inclement weather, excessive heat, cold and rain. Cool places with good ventilation are preferable to warm, close stables.

Care – Horses are cleaned and groomed every day. Proper grooming keeps the horse clean and helps in imparting a glossy and shining coat to the skin. Massaging stimulates blood circulation and provides a short of passive exercise. Hooves are cleaned regularly.

Feeding – In feeding horses, regularity is very important. They are fed on oats, barley, gram and hay. Green grass can be substituted for hay. Common salt is added to their diet.

Breeding – Horses, as compared to other animals, have a low reproductive rate. They are more difficult to breed and have a long gestation period. Horse-breeding by controlled natural mating has been in practice for long time in our country.

Rearing, training and medical care of the race and polo-horse needs high professional skills.

Dunkeys .– Dunkey is the most simple and unselfish animal. It can withstand adverse weather conditions. It is a hardy animal and can work incessantly without rest on poor forage.

Its food is simple. It can live on a small quantity of straw and fodder.

There are two types of donkeys in India – grey and large white. The small grey donkey is found in most parts of the country. The large white type is mostly found in the Kathiawar region of Gujarat state.

Some of the important foreign breeds of donkeys are the White Egyptians, the Damascus, the Persian and the Arab. The Poitou donkey of France is the largest and the Indian ass is the smallest in the world.

Mules .– A mule is a hybrid of a male donkey and a female horse. The hybrid from a reciprocal cross is called henny.

Mules show hybrid vigour. They are sturdier than the horse and larger than the donkeys. Both male and female mules are infertile.

Female donkeys have been imported by the Indian army from Europe for breeding mules. Mule is the most favourite pack animal in the rugged hilly tracts. It is a firm footed animal that can carry heavy loads on steep Himalayan terrain.

Mules are fed with green fodder, gram, barley and salt. To keep them is good working conditions, they need constant care and attention. They are less susceptible to diseases.

ELEPHANT

Elephant is the largest land animal. It was used in war, for religious purposes and in royal processions. It is regarded in India as a remover of obstacles and a symbol of good fortune. It has occupied an integral part of social, religious and economic life in several parts of the country.

Elephant is a friendly animal. It is used in temples and circuses. It is employed for hauling logs of wood in hilly areas and dense forests. Tusks of elephants are used for carving. Ruthless killing of elephants for ivory has resulted in its dwindling population. Thus trading in ivory has been banned all over the country.

CAMELS

Camel has been aptly described as the ship of the desert. It is the valuable beast of burden and transport in the hot and arid desert regions.

Adaptations for Desert Life

1. Extraordinary power to resist thirst and hunger.

2. It can live as thorny shrubs.

3. Long neck and thick foot pads for movement on loose hot sands.

4. Thick skin over the body to present water loss.

5. Long eye lashes to prevent the eyes from sand.

6. Hard lips to browse thorny bushes.

7. Hump acts as an emergency food-store in the form of fatty tissues to enable it to live under drought conditions.

Types of Camels. There are two species of camels. The *Bactrian* camel is an inhabitant of Central Asia. It has two humps. The second is *Arabian or Dromedary* camel with one hump. In India, only the one-humped camels are found. The Arabian camel is less heavily built and longer in the hind. Its skin is soft and comparatively thin.

Uses – Camel is used for riding, carrying loads, ploughing and threshing grains. It is also used for pulling carts, drawing water from wells. It is used as a motive power in sugar cane and oil seed crushing mills. Hair of camel are used for making garments, brushes and cords. Its dung is used as fuel. Hide provides leather for making saddles. Camel's milk and meat are taken by the desert dwellers.

Breeds of Camel – India is one country which is engaged in camel husbandry. Common Indian breeds are Jaisalmeri, Sindhi and Bikaneri of Rajasthan. Kutchi breed is found in Gujarat.

Housing and Feeding – Camels are kept in simple and ventilated sheds. A sand bedding trough in which water is sprinkled in the evening is regarded comfortable for the night rest.

Camels are fed on dry fodder mixed with chopped green fodder made of pulses, mustard and green peas. With the help of long neck, camels are able to browse on trees, shrubs and bushes.

Breeding Season – Camel has a well-defined season of breeding. It comes into rut during winter months – November to March. The actual duration of the rut depends on the general condition of the animal. The gestation period is long ranging from 375 to 392 days.

Diseases – The common diseases of camel are anthrax, pneumonia, camel-pox and surra.

POULTRY

The term 'poultry' includes fowls, ducks, geese, turkeys, guinea fowls and pigeons, but it is more often used for fowls. Keeping fowls for eggs, raising browlers for meat, poultry-breeding and hatcheries are the common poultry enterprises. Other allied professions are egg and meat processing, egg and poultry marketing, processing and sale of food, poultry equipment.

Although India and neighbouring countries are considered to be the ancestral home of the jungle-fowl from which the modern domestic fowls have descended, it is only recently that attention was given to poultry in this country. Poultry production was considered uneconomical owing to low egg production, low prices for eggs and chickens, and fear of contagious diseases.

Poultry farming has now become popular, and many of the farms have several thousand layers. The factors favourable for the growth of poultry farming are : small initial investment, quick return,

requirement of small area and use of various kinds of foodstuffs.

Production of Eggs and Meat

The average production of an Indian breed is about 60 eggs per annum. Several high-yielding varieties have been developed which can yield upto 240 eggs per annum. The total production of eggs in 1973-74 totaled 770 crores which increased to 1232 crores in 1979-80. The target for 1984-85 has been kept at 1630 crores of egg production.

The annual per head consumption of poultry meat and the eggs is shown in the tables below:

Table 50·5: Average per head poultry meat consumption

USA	13.18 kg
European countries	2.5-5.9 kg
India	131 gms.

Table 50·6: Average per head consumption of eggs

USA	295
Canada	282
W. Germany	249
India	6

Feeding the Poultry Flock

Unlike the feed of other livestock, the poultry is not dependent on any specific feed. The hen is quite efficient in converting the feed unacceptable to man into food products of high nutritional value. Carbohydrates, fats, proteins, minerals, vitamins and water are the essential nutrients required by the poultry. The feeds given to the birds consist of cereals and cereal byproducts of corn, wheat, rice and millets like jowar, ragi and bajra. Oil cake, protein concentrates, fish meal or meat meal, minerals and greens are also included in the feeds.

Poultry Housing

One of the most important aspects of sound poultry farming is to house the birds properly. The maximum yield of eggs is obtained by keeping the poultry comfortable, well ventilated, dry, clear and properly lighted house. It should be reasonably cool in summers and warm in winters.

Birds of different ages should be kept separately. The cage method of housing is followed in areas of moderate climatic conditions. Floor or loose housing or litter system is most suitable for Indian climatic and economic conditions. In loose housing, the birds are free to wander about and the floor is covered with litter. Chopped straw, paddy husk, groundnut hulls or dry leaves are used as litter.

The poultry houses are protected from rats, fox, cat, snakes, dogs and kites etc. Good drainage system is essential to keep the poultry yard clean. Running water channels should be provided to ensure fresh water supply.

Disease and Control

Different types of diseases and lack of proper feed take a heavy toll of poultry. Ranikhet, Coryza and fowl cholera are the diseases which lead to the death of a large number of poultry in no time. The various diseases of poultry can now be controlled by preventive measures like good management, proper nutrition and timely vaccination of the newly born chicks. Sulpha drugs and antibiotic treatment have been found to help in curing several diseases. Overcrowding of birds should also be avoided. Poor ventilation and dampness favour the spread of diseases.

The infected birds should be separated immediately from the healthy birds and veterinary help to be taken to check the spread of diseases and their cure. The diseases may affect the birds at various ages and may result in a drop in egg production. Some of the important diseases of poultry are given below:

1. **Viral diseases**—These are Fowl fox and Ranikhet or New castle disease.

2. **Bacterial diseases**—These include Fowl Cholera, Solmnellosis and Coryza.

3. **Fungal diseases**—Aspergillosis.

4. **Parasitic diseases**—The parasites are of two types—

   (i) *Internal parasites* — Roundworms, tapeworms and thread-worms.

   (ii) *External parasites* — Fowlmite, Chicken-mite, fleas, ticks, lice, etc.

Breeding

Aseel, Busra, Ghagus, Brahma and Cochin are the pure breeds of India. Of these Aseel is one of the best table birds with plenty of flavoured flesh. The desi birds generally have poor egg laying capacity.

For poultry breeding two aspects are kept in mind (i) improving the birds for poultry meat and (ii) improving the birds for more eggs. For meat fast growing chickens are selected. When the production of eggs is the prime consideration, the high egg-laying varieties of chickens are selected. The hens with characters for high egg production give better results.

Cross-breeding is done between the males and females of desired characters. Cross-breeding has resulted in higher rate of hatching of eggs, more efficient and faster gains in weight and lower rate of chick mortality. Hybrid vigour has proved to be of extensive utility in broiler production.

Some of the exotic breeds utilized for the improvement of egg production in our country are White Leghron, Rhode Island Red, Plymouth Rock, New Hamphshire, Orpington, Australorp, Sussex and Minorca. Quite a large number of these birds have been imported, bred and acclimatised to local conditions. Some of these varieties are good meat-producing while others are excellent egg-layers.

Cross-breeding has helped in raising the egg production considerably. Some of the hybrids yield as many as 230-240 eggs a year and have a low mortality rate. Poultry meat production has also increased many times as hybrid broilers (birds grown for meat) have a fast growth and high nutritive value.

Ducks .— The second most important kind of poultry in India is ducks. Ducks thrive well on any soil, preferably where semiaquatic conditions prevail. These comprise 6 per cent of the total poultry production in India. They are abundant in the Southern and Eastern parts of India.

India produces 402 million duck eggs every year. This is nearly 16 per cent of the total egg production in the country. Duck eggs are heavier than the hen eggs, and weigh from 70 to 84 grams each. Ducks are more hardy than fowl and are practically free from diseases. They do not require as much attention as fowls.

Table 50.7: Important breeds of ducks

Indigenous	Exotic
1. Indian runner	1. Muscori
2. Syhlet mete	2. Pekin
3. Nageswari	3. Aylesbury
	4. Campbell

Geese

Brown and white geese are common in India. Geese are raised mainly for meat production. The important breeds of geese are Emden, English White, Roman, White Chinese, Farn Chinese, English Grey and Indian goose.

Turkeys

Turkeys have gained popularity during recent years. They are reared for meat. The important breeds are Narfold, British White, Broad Breasted Bronze and Bellsville Small White.

FISHERIES

Fish constitute an important and plentiful source of high quality animal protein. Fish proteins occupy an important place in human nutrition because of their high digestibility and growth-promoting value. Fish are also the rich source of minerals like calcium, phosphorus and iron. India abounds in fish, both freshwater and marine. Fishery development has received a high fillip in recent years in view of its vast potential as a protein rich source of food.

Keeping in view the importance of fishing industry and the potential of employment opportunities, Government has given due importance to the development of fishing industry.

Our country has a coastline extending to about 4700 km. in length and a continental shelf of 2.59 lakh sq. km. area bordering the coastline. In addition to this, the offshore and coastal areas of Andaman-Nicobar, Lakshadweep and Minicoy islands, and mangrove marshes are an abundant source of marine fishes. Along with this the inland water consisting of 27,300 km. of rivers, about 1,12,650 sq. km. of canals and irrigation channels, and several tanks, ponds and reservoirs provide excellent locations for inland fisheries. The fish production by proper utilization of fresh water, brackish water coastal areas is called *aquaculture*. Aquaculture has a

significant role in increasing the production of protein-rich diet and serves as a base for many ancillary units. It also provides avenues for employment. Fast growing fishes are selected for aquaculture.

The total fish production in our country during 1985-86 amounted to 285 lakh tonnes. India is at present among the first six sea-food-producing countries. India is also emerging as one of the biggest exporters of sea-food to other countries.

Inland or Freshwater Fisheries

India has extensive inland water bodies which sustain fisheries of commercial value. The term inland fisheries is generally used to include not only freshwater but brackish water fisheries also. The principle types of water areas are ponds, tanks, lakes, rivers, reservoirs, irrigation canals, estuaries, back-waters and marshy swamps. These water areas cover nearly 9.6 million hectares and the potential yield from these is estimated to be about 7 million tonnes of fish per year. At present freshwater fish landing are little over 0.6 million tonnes.

The inland fisheries can be divided into *culture fishery* and *capture fishery*. In culture fisheries, also called *pisciculture,* the fish seed has to be sown, tended, nursed, reared and finally harvested when grown to table size. In the case of *capture fisheries,* which pertains to the rivers, estuaries, large reservoirs as well as big lakes, man has only to reap without having to sow. Some important fresh-water culturable fishes are as follows:

1. *Catla*
2. *Labeo*
3. *Cirrhinus*
4. *Barbus*
5. *Cyprinus*
6. *Mystus*
7. *Channa*
8. *Clarius*
9. *Heteropneustes*
10. *Tinca*

Marine Fisheries

Marine fishery deals with the fishery aspects of the sea water or ocean. Till now sea fishing in India was confined to a narrow coastal region, leaving the off-shore and deep-sea regions left unexplored. A recent survey has revealed abundant resources of sardines and mackerel off the south-west coast. To tap fish from the sea, mechanisation of fish industry

has been taken in hand. Fishing harbours are being developed at major ports in the country. In addition, about 70 small and self-contained harbours were completed by 1979-80. Fishing trawlers fitted with sophisticated electronic fish-locating equipment have also been procured to give a fillip to deap-sea fishing. An Integrated Fisheries Project located at Cochin is engaged in the exploration and utilization of marine resources. This is the biggest project of its kind in south-west Asia.

Some of the important marine fishes of our country are —

1. *Hilsa*
2. Mackerels
3. Bombay duck
4. Catfish
5. Ribbon fish
6. Red mullet
7. Flying fish
8. Sardines
9. Oil sardine
10. *Mugil*

Transportation and Storage of Fishes

The exports of marine products have been increasing significantly over the past few years. But, due to inadequate refrigerated storage and transport facilities, there has been considerable spoilage and wastage of the catch. In recent years facilities for cold storage and refrigerated transport of fish within the country have been developed. The efficient functioning of fisheries corporations and cooperative Federations is being encouraged for fish seed production, reservoir development, marine fisheries exploitation, and processing and marketing of fish for internal consumption and for exports.

Aquaculture

Aquaculture involves production of useful animals such as fishes, prawns, shrimps, lobsters, crabs and molluscs. The process involves utilization both of small and large bodies of water.

Pisciculture .— Pisciculture is the production of fishes. Some food fishes, especially the carps are cultured in ponds and tanks or in special breeding grounds near the river banks. Fish forms are produced for large scale fish farming. The fish farms are built of a chain of ponds or tanks fed by running water.

Fish eggs are introduced into nurseries in hatcheries. The young ones hatched from the eggs are fed, tended and nursed in nurseries. The fish fry

about an inch long are transferred to rearing tank for 4-6 months. When fully grown the fish are harvested.

Induced breeding by the administration of pituitary hormones help in the production of seed fish in pure form. 100 per cent hatching of fertilised eggs has been obtained by circulating water in the hatcheries.

Uses of fish

1. Fishes form a protein rich diet for human beings.
2. Shark liver oil and cod liver oil are natural sources of vitamins A, C and D.
3. Oil from sardines, herrings and salmon is used in the manufacture of soaps and paints.
4. Fish meal is a rich source of protein for cattle and poultry. It is obtained from the wastes such as tails, fins and bores.
5. Fish-waste is also used for making fertilisers and adhesives.
6. Skin of shark is used for making shoes, hand bags and other fashionable goods.

Crustaceans Fishery

Crustaceans constitute the most important class of marine fisheries of the country. They include prawns, lobsters and crabs. Indian prawn industry constitutes 18 per cent of the world production. The annual catch is about one lakh tonnes and is second only to the U.S.A. Prawn pulp is exported to several countries.

In recent years lobster fishery has gained much importance due to the growing demands for lobsters in the foreign countries. The edible part of the lobster is the lobster tail of commerce. Lobsters are exported in frozen state. Their heads are removed and the tails are kept in polythene bags.

Crabs are distributed all along the Indian coastal line. Crabs are considered as popular food item in India. Crab concentrate prepared from the crab meat is a popular delicacy in foreign countries.

Molluscan Fishery

The commercial culture of molluscs such as edible oysters and mussels had been old practice in European countries and Japan.

The bivalues, gastropods and cephalopods are the molluscs of economic importance. This group constitutes a good percentage of sea food. Pearls and shells are also very important articles of trade. In India, the important molluscan beds are found along the west coast and the Palk Strait and the Gulf of Mannar.

QUESTIONS

1. 'Buffalo is a better dairy stock than cows.' Justify this statement.
2. What is feed? Give its classes and also the constituents of each class.
3. Breeding improves the animals in terms of yield and resistance to diseases. Illustrate your answer with suitable examples.
4. List the common breeds of cattle and buffaloes of our country.
5. Name the common breeds of sheep and goat.
6. Compare the annual average milk yield of Indian cow with that of other countries.
7. What do you understand by live stock ?
8. Suggest some measures to improve milk production in the country.
9. Write a brief account of poultry in India.
10. What do you understand by poultry ? Describe in brief the poultry housing and the diseases and their control.
11. What constitutes the feed of poultry birds.
12. What is the role of breeding in poultry farming ? Give examples.
13. Name of the common diseases of poultry and how they can be controlled.
14. Why it is advised to use good breeds ?
15. Give the present availability of eggs per year in different countries.
16. Name some exotic breeds of fowl.

17. Mention the names of some common desi breeds of fowl.
18. How many eggs a desi fowl produces a year ?
19. How many eggs a hybrid produces in a year ?
20. Give a short account of fisheries in India.
21. Define the term aquaculture.
22. Explain the term pisciculture.
23. Write an explanatory note on inland fisheries.
24. What do you understand by marine fisheries ?
25. Name three fresh water fishes.
26. Write the names of any two marine fishes.
27. What was the total fish production in the year 1979-80 ?
28. Write down the approximate length of the Indian coastline.
29. What kinds of animals did early man domesticate ?
30. What is the role of livestock in the agricultural economy of India ?
31. Explain the terms - breed, feed, artificial insemination, random breeding, embryo transplantation.
32. How are mules produced ? Explain their benefits and limitations.
33. Name three diseases of livestock and three diseases of poultry. How they are controlled ?
34. Write adaptive characters of camel enabling it to live in desert. How camel is useful to man ?
35. What are the new methods used for increasing fish production ?
36. Name three common fresh water, and three marine edible fishes.
37. What is the benefit of cross-breeding of Indian sheep with the merino sheep ?

CHAPTER 51

Improvement of Animals

Animal breeding and selection is conducted for obtaining animals with large size, rapid growth, sturdy body build, better meat quality high milk yield or improved quality of eggs or wool. Another aspect of breeding and selection is to establish disease resistant races. Sheep, goat, pig, fowls are bred for food, cattle and goat for milk, sheep for wool, rabbit for fur and cattle for leather while the donkeys, camels, oxen, pony and mules are reared as beast of burden.

The improvement of animals is brought about by selection for desirable tracts by

1. Inbreeding and selection.

2. Outbreeding or hybridization and selection.

3. Artificial insemination.

1. INBREEDING

The process of mating among closely related individuals is known as **inbreeding**. There can be different degrees of inbreeding. The self fertilization in plants as in peas and beans is the most intense form of inbreeding. In 1903 JOHNSSEN recognised the uniformity that is found in self fertilizating plants grown in the same environment. He called such fertilizing true breeding populations as **pure lines**.

The cross fertilization in plants and animals affords different degrees of inbreeding based on kinship. For example, marriages between brothers and sisters, betwcen the first cousins and second cousins are examples showing different degrees of inbreeding.

1. Inbreeding tends to decrease variations within the group, maintains homozygosity and stabilizes the type. Therefore, breeders have developed a desirable genotype in a group by controlling the matings of the animals within a herd of flock. Registered breeds are obtained in this way.

Inbreeding combined with selection over a period of time has resulted in many valuable breeds of domestic animals. For example :

(*i*) **Merino Sheep** known for producing fine wool are developed in Spain as a result of inbreeding and selection conducted for about 170 years. Rambouillet sheep were developed in France from Merino breed.

(*ii*) Modern race of **horses** are the descendents of three Arabian stallions imported into England between 1686 and 1730 and mated with several local mares of the slow and heavy horse type.

2. HYBRIDIZATION

Hybridization is practised for creating new breeds. Some examples of hybridization or controlled breeding are —

1. A cross breeding between *white short horn* and the *black Angus cattle* produces a *blue roan hybrid* which had the vigour, rapid growth, economical utilization of food and high quality of beef.

2. A cross between *Brahman bull,* a race found in India with *domestic cattle of European origin* produced hybrids which showed greater adaptability to warm and humid climate.

3.ARTIFICIAL INSEMINATION

Despite having a large number of livestock milk, meat, eggs and other animal products are in short supply in India. The reason is that the improved breeds of these animals are just a few and not sufficient for controlled breeding. The problem had been overcome by the development of technique of **artificial insemination**. In India it was first exercised in 1944 at *Indian Veterinary Research Institute, Izatnagar*. In this method the semen from the better quality bulls is collected, stored and artificially introduced into the oviducts of females. The semen can be preserved for long time and be transported to inseminating centres in the country or outside.

Advantages of Artificial Insemination

1. It is very economical and makes possible a wider use of superior bulls. A bull normally produces 50 to 60 calves per year by natural mating. By restoring to artificial insemination it is possible

to produce about 1000 calves in a year from one bull.

2. The semen can be collected from the bull and used at distant places, while transportation of bull is not practicable.

3. The spread of diseases can be controlled.

Introduction of New Varieties

A large number of foreign breeds of cows, bulls, buffaloes and other animals have been introduced in India. Some of these are : Jersey (England), **Ayrshire** (Scotland), **Brown Swiss** (Switzerland), **Holstein, Freisian** (Holland), etc. By cross breeding with Indian varieties following hybrid varieties have been developed : Jersey-Sindhi, Ayrshire-Sahiwal, Brown Swiss-Sahiwal etc. Animals like chicken, ducks, pigs, boars, etc. have also been improved by introduction. Boards of foreign breed like Large White Yorkshire, Middle White Yorkshire and Berkshire have been introduced in India for improving Indian pigs.

QUESTIONS

1. Why the improvement of animals is necessary ? Comment.
2. How the improvement of animals is brought about ?
3. What is artificial insemination ? Mention its utility in the improvement of animals.
4. What is inbreeding and selection ?
5. Write short notes on the following:
   (i). Introduction of new varieties
   (ii). Breeding
   (iii). Inbreeding
   (iv). Artificial insemination.

□ □

Insects and their Products

Some tiny insects produce raw materials for various industries. Some of the important varieties of insects are bees, moths and lac insects. The economic importance of these insects was realised with advancing knowledge of science.

APICULTURE

Apiculture is the care and management of bees. Bees produce honey and wax and are named as honey bees. Their description is found in Vedas and Ramayna. The earlier methods of bee-keeping were crude and uneconomic. This resulted in wastage of honey and also the death of insects. It was only in the 19th century that the use of improved techniques was made. It involves the introduction of movable frame hives and honey extraction.

Benefits of Modern Method

1. Activity of honey bees can be kept under control.
2. Sugar and pollen grain can be provided to the members of the colony to get healthy colony of bees.
3. Absconding of bees can be avoided.
4. Hines can be protected from ants, wasps and rats.
5. Same hive can be used again and again.
6. Hive can easily be transported from one place to other.
7. Pure honey can be obtained.

Bees

Apis dorsata, A. florea and *A. indica* are the common species of honey-bees in our country. Honey-bees help in pollination in the nectar-producing flowers. Bee-bites have sometimes helped to a great extent to treat the muscular, nervous and sciatic pain and rheumatism.

Apiary— It is the place where bees are cultured and bred to get commercial products.

Bee-keepers can make bee-keeping profitable in the following ways:

1. By having a definite number of colonies
2. Strong colonies of desirable strains.

3. By having means to get and sell pure honey.
4. They should have the knowledge of honey-producing plants and honey-flow conditions of the locality.

Products of Bee-keeping

We get honey and wax from honey bees –

1. Honey – Honey is very nutritious. It contains 40% sugar. Its composition is —

1.	Levulose	38.10%
2.	Dextrose	20.28%
3.	Maltose	8.81%
4.	Enzyme	2.21%
5.	Ash	1.00%
6.	Water	17.20%

Honey is used as rich food and medicine.

(i) **As food** – About 200 g. of honey is said to be equivalent to 9.15 litres of milk or 1.6 kg butter or 330 g meat. Its sugar, minerals, vitamins can easily be assimilated in the body. It can be used in all seasons and by all persons of different age. It can be used in the preparation of cakes, bread, candy etc. It is very good for patients.

(ii) **As medicine**—Honey is used in Unani and Ayurvedic treatments. It act as a laxative, sedative and antiseptic. It can be used in cough, cold, fever. It purifies blood and helps in the synthesis of haemoglobin. It is useful in ulcers of alimentary canal, indigestion and under nourishment. Its use destroys typhoid bacteria in 48 hours. By using honey dysentry can also be cured within 48 hour.

2. Bee Wax – Bee wax is yellowish, brown. It is insoluble in water but soluble in ether. It is used in preparing cosmetics, like cream, ointments, polish and carbon paper etc.

Bee-keeping Industry

It is an important industry in America, Canada and Austrialia. In India it is a small scale industry. It can be extends to villages where it can help in

improving economic status of villagers and can provide better opportunities of employment.

SERICULTURE

The breeding and management of insects for the production of silk is known as *sericulture*.

History of sericulture Industry

Long long ago, about 3500 B.C. It was in China that people first raised *Bombyx mori*, the silk moth, and manufactured silk. According to Chinese historians the discovery of silk was made by the wife of Chinese Emperor, Hoang Ti Si-ling-chi. But it was kept a secret for long. Somehow the secret was smuggled out of China through some monks. It was introduced in Japan about 1,700 years ago and in Europe in 522 A.D. Today sericulture is practised in many countries in the world.

Silkworm

Bombyx mori is a native of China but has been successfully domesticated in India, Japan and in many other countries. It occurs on mulberry leaves and is now commonly known as **mulberry silkworm**. The silk produced by *B. mori* is white or light yellow and is of a good quality. By careful selection and hybridization many new races have been developed and found suitable for different climates.

Economic Importance of Silk Moth

Silk moths are reared for obtaining silk. The rearing of silk moth is called **sericulture**. It is a big industry in China, Japan, Italy and France. In India silk-moths are reared in Kashmir and Mursidabad district of Bengal. In India there are following genera and species of silk moth :

(i)	*Attacus ricini*	– Wild silk moth
(ii)	*Antheraea assama*	– Eri silkworm of Assam
(iii)	*Antheraea paphi*	– Munga moth of Assam
(iv)	*Aassama*	– Tasar silk moth
(v)	*Bombyx mori*	– Domestic silk moth (native of China)

LAC CULTURE

Lac is the resinous secretion produced by lac insect as protective covering around its body. It belongs to genera *Laccifera* or *Tachardia*. *Laccifera* *lacca* is the common Indian lac insect. It lives on the trees of fig family namely, kikar, ber (*Zizyphus mauritiana*), babul (*Acacia nilotiana*), dhak or palas (*Butea monosperma*), Kusum (*Schleichera oleosa*), Katha or khair (*Acacia catechu*), peepal (*Ficus religiosa*), gular (*Ficus glomerota*).

Lac insect feeds upon the sap of its host plant like any other sap sucking insect. It is found in India and Philippine islands.

Lac Cultivation

In order to obtain lac, lac insects are cultured and the technique of lac production is known as the *lac culture*. It involves proper care and regular prunning of the host plants, propagation of insects, and collection and processing of lac. For the purpose of propagation the older branches containing crusts are tied with new branches and this method is called *oculation*. When new crusts are formed, the old twigs are removed (approxmiately 20-30 cm long) and this is known as *harvesting*.

After inoculation, lac insects come out of the old crusts. At this stage they are known as *nymphs*. The nymphs hatch out from eggs laid by the females in the old crusts. The coming out of nymphs from the old crusts is known as *swarming*. Some of the nymphs become winged or wingless male and others become female. These nymphs explore new branches. The thousands of nymphs settle side by side, and the resinous secretion builds up arounds them and completely encases them. The nymphs undergo several moults. Most of them develop into females and some into males. The females remain in small cavities in the resinous mass from which they never come out.

Extraction of Lac

The largest yield of lac and dye are obtained by harvesting the infested twigs where females are still living. The harvesting is done twice a year in June and November. The encrusted twigs are pruned and lac scrapped from them. This is known as *stick lac*. It is grounded and sieved. The resulting granular lac is called **seed lac,** and the fine particles the **dust lac.** The seed lac is washed, melted, spread out in a thin layer, and dried thus forming the **shellac** of commerce. The dust lac is used for making toys, shellac is used in the preparation of varnishes, paints and polishes ; in making gramophone records buttons and pots; and

in filling ornaments like bangles and bracelets. It is also used as insulating material.

Lac insects are highly useful to man. They yield lac, the utility of which is discussed above. Besides this, a red dye is obtained from the body of female insects. The dye is used by women to colour the soles of their feet, skin and wool. Lac insects are also used for curing lung and stomach troubles.

Economic Importance of Lac

Lac is used in the preparation of sealing wax (shellac), paints, varnish, in the manufacture of photographic materials, electrical goods. Lac is also used in the preparation of bracelets, buttons, toys and in filling hollow gold ornaments. Lac is also utilized in confectionary trades and in artificial leather and pottery. Gramophone industry used to consume 30–40% of the annual production in the preparation of records.

Cultivation of Lac in India

India has monopoly in the production of lac. It is about 75% of the world's total output. Approximately 40 lakh ponds of lac is produced. Bihar, M.P. and West Bengal are major lac producing states in India. Thailand is major competitor of India as it shares 25% of the total export. India exports about 1,80,400 kg. of lac. The use of lac is being gradually replaced by plastic.

QUESTIONS

1. Define the term sericulture.
2. Write briefly the various uses of honey and bee-wax.
3. How apiculture can help in better living ?
4. Mention the uses of honey.
5. Write two medicinal uses of honey.
6. What is lac ? Give the scientific names of the inseil and the host plant.
7. List the three species of honey bees.
8. How lac is useful to man ?
9. Name two genera of silk moth and the type of silk produced by them.
10. What will happen if all mulberry trees from silk producing region are suddenly destroyed ?

CHAPTER 53

Bioenergy

ALICH and INMAN (1975) and JEWELL (1978) have described the role of biomass as alternative source of clean and renewable fuel and energy which can greatly replace our future dependence on fossil fuels. Photosynthetic fixation of solar energy results in the production of biomass, which can be used directly as with wood combustion for energy generation or indirectly for development of other more specialised energy containing products such as alcohols and methane gas.

Today there is optimism that biomass will be able to contribute significant amount of energy for our future needs. Animal residues represent the lowest potential source of biomass, but in our country with a vast cattle population, it can play a significant role in meeting the needs of energy and fertilizer.

Bioenergy is the energy obtained from biological sources. It can be broadly classified into **animal energy** and **biofuels**. Coal, petroleum and natural gas, though of biological origin are classified as **fossil fuels**. Firewood, agriculture waste and cow dung which form 90% of the total energy consumed in rural areas comprise of about half of the total energy consumed in the country.

Animal Energy

There are two forms of animal energy. Human Muscle Power (HMP) and Draught Animal Power (DAP).

1. **Human Muscle Power (HMP)** — This form of energy is widely used by woman in their household jobs and by small farmers, artisans and non-agricultural labourers. HMP forms a significant part of the energy utilised. It is roughly one-fifth of the total electricity generated in our country.

2. **Draught Animal Power (DAP)** - Domesticated animals are used in agriculture and for transport. These animals play an important role in the rural areas. Because of poor quality of animals and outmoded design of carts and agricultural machinery, the full potential of Draught Animal Power (DAP) has not been realised. This can be

achieved by the following :

(i) Improvement of carts.

(ii) Proper management of grazing lands and pastures.

(iii) Production of nutritious fodder.

(iv) Breeding only improved draught animals.

There are about 84 million work animals in our country. Of these 70 million are bullocks, 8 million buffaloes, and two million horses and camels. In addition to these elephants, yahls, donkeys and mules are also used as draught animals.

Energy potential of DAP is enormous. If 0.5 hp is generated by each animal, the total installed capacity of the draught animals comes to 42 million hp or 30, 500 MW. This is just equal to the total installed electric power generation in the country.

In India over 50 per cent of the farmers have less than two acres of land each. Because of it they are not able to use tractors. Thus DAP has an important place in one energy scenario. Further, there are more than 15 million animal drawn carts in the country. Carts have an advantage that they can be used on all types of roads and in all terrains.

BIOFUELS

Biofuels are a major source of energy. The biofuels are renewable. Thus, when used properly and efficiently, they can solve energy problems of developing countries. With the help of latest available technology, there seems to be a possibility of replacing fossil fuels by biofuels.

Biomass can be used as a source of producer gas to run water pumps for irrigation, to obtain alcohol, to replace petrol, to generate biogas for cooking and lighting and to generate electricity.

Sources of biofuels — Biofuels are obtained from following sources :

1. Wood

2. Agriculture residues

3. Agro-industrial wastes

4. Animal Wastes

5. Plants that produce oil, alcohol and petroleum.

Methods of obtaining Energy from Biomass:— The various ways of utilising biomass as fuel are given below :

Biomass	Process	Form of Energy Produced
1. Wood	— Direct burning	Heat
	— Gasification	Producer gas
	— Carbonisation	Charcoal, gas, oil
	Hydrolysis and fermentation	Ethanol
	Gasification and synthesis	Methanol
2. Agro-industrial residues	Anaerobic digestion	Biogas
3. Plants producing petroleum and oil	Direct use Cracking	Petroleum products, Heating, running engines

1. WOOD

Direct Burning

Man has been using wood since he discovered fire. Over 50% of the global population uses wood for heating and cooking. Wood is also used in industries for heating. In 1984, world consumed 1.7 billion tonnes of wood. Two-thirds, of this was used by developing countries in Asia and Africa. Such massive and liberal use of wood has resulted in extensive deforestion resulting in degradation of environment.

Advantages of Wood as a Fuel

The principle advantages of wood as a fuel are :

1. Widely available source of renewable energy.

2. Can be harvested by unskilled labour.

3. 99% of it is combustible.

4. It produces flame and can be used for heating large surfaces.

5. Wood from most species of plants can be used as fuel.

Characteristics of Firewood

1. It should be highly combustible.

2. Should have a high calorific value.

3. Should be free from offensive odours.

4. Should be easy to dry and not split when ignited.

Hardwood (obtained from dicotyledons) is better than soft wood (gymnosperms) as fuel. Hardwood produces uniform heat over a long period of time, whereas soft wood burns rapidly to produce intense heat but for short period only. Following are the good and bad firewood sources in India:

Good Firewood

1. *Acacia nilolica* (Babul)
2. *A. senegal*
3. *Anogeissus latifolia*
4. *Azadirachia India* (neem)
5. *Casuarina equisetifolia*
6. *Ceriops tagal*
7. *Adina cordifolia* (haldu)
8. *Albizia spp* (siris)
9. *Dalbergia sisoo* (sheesham)
10. *Mesua ferrea*
11. *Quercus spp.* (Oaks)
12. *Prosopis cineraria* (Khejri)
13. *Syzygium cumini* (Jamun)
14. *Terminalia toinentosa*
15. *Heritiera minor* (sundri)
16. *Lagerstroemia sp.* (jarul)

Following widely distributed species of plants are unfit as fuel :

1. *Mangifera indica* (mango)
2. *Madhuca indica* (mahua)
3. *Michelia excelsa* (champak)
4. *Bombax ceiba* (semal)
5. *Bauhinia racemosa* (kachnar)
6. *Pinus roxburghii* (chir)

Fuelwood Crisis

Two billion people in the world depend on wood as fuel for cooking and heating. Of these only 0.5 billion are able to get enough firewood while the others face difficulty in obtaining their meagre average supply of 3kg per day. The rising population and unequal economic growth of the developing countries put a high demand on fuel wood and additional land to produce more food. This leads to deforestation which ultimately results in soil erosion and silting up of dams.

Consumption of firewood in India is about 146.5 mt and is expected to rise to 258 mt by the year 2005. To meet this ever increasing demand, India is loosing 1.3 million hectares of forests every

year. Due to scarcity of firewood, rural women spend a major part of the day in collecting wood.

Following steps have been suggested to meet the energy crisis—

1. To raise *energy plantations* by growing more fuelwood trees.

2. To improve the efficiency of wood stoves by proper design.

3. To extract energy from wood efficiently by carbonisation and gasification.

4. To make use of electric crematory for cremation.

Energy Plantations

Supply of firewood can be assured by establishing energy plantations near the source of consumption. Energy plantations have following advantages:

1. Solar energy can be stored continuously.

2. They need minimum input.

3. Sufficient and cheap manpower is available for raising them.

4. They are economical and ecologically safe.

5. They are renewable.

Following points are related to the raising of energy plantations :

1. **Mobilisation of land resources —** Per capita availability of land is likely to decrease from 0.29 hectares in 1971 to 0.17 hectares in 2000 A.D. Thus it is clear that no agricultural land could be diverted for fuel wood trees. Following alternatives have been suggested to grow fuelwood trees :

(*i*) To grow fuelwood trees on farmer's land.

(*ii*) To make use of village common lands for fuelwood.

(*iii*) To grow such trees on either side of the roads, canals and railway tracks.

(*iv*) To grow fuelwood trees on waste lands and in degraded forests.

It is estimated that over 30 million hectares of land can be made available in our country for raising energy plantations without diverting land under agricultural and industrial use.

2. **Selection of suitable species —** Species selected for energy planations should have multiple uses, like fruits, seeds, fodder, green manure, tannins and medicinal products in addition to firewood. *Social forestry* means raising of forests by the community for obtaining firewood, fodder, timber etc.

3. **Development of agro-technology for energy plantation —** To maximise yield, techniques of growing individual species in specific habitats must be worked out. For maximum land use grasses and fodder crops should be grown along with fuelwood.

Criteria for Selecting Suitable Species for Energy Plantations.

1. Selected species should be local ones since they are better adapted to climatic and soil conditions.

2. Saplings should be able to establish themselves easily and show rapid growth.

3. Species should have high coppicing ability. Coppicing means that once the tree is cut, growth of thick branches takes place from the slumps. These branches can be cut repeatedly to provide firewood.

4. Species should have low requirement of water and fertilizer.

5. Species should be able to improve soil quality.

6. Species should be free from pests and diseases.

7. Wood of such species should have a high calorific value and burn without producing toxic gases.

8. Species selected for arid regions should have low transpiration losses.

9. Species should impose minimum drain on nutrients.

10. Since fuelwood trees have a short rotation time, only a little leaf litter is available. Thus species with high nitrogen fixing capacity are desirable.

2. **Gasification**

Gasification is a technology for connecting a solid energy source into a gas. Wood in cubes of about 25% moisture is one of the best raw materials

for gasification. The gas so produced is called *producer gas.* It is a mixture of gases consisting of combustible CO, H_2 and a little CH_4 with CO_2 and N_2 as noncomustibles.

The composition of a typical producer gas derived from a coconut shell is as follows :

—CO	23.0%
—H_2	18.3%
—CO_2	8.8%
—H_2O	3.8%
—N_2	46.0%
Total	100.00%

Producer gas intended to be used for heat generation and cooking needs no treatment . On the contrary, gas for use in combustion engines has to be cooked and cleaned.

3. Charcoal

Women in India who cook food by burning biomass fuels like wood or cowdung expose themselves to high levels of pollutants, including a deadly chemical, *benzo-a-pyrene*, which is suspected to cause cancer.

Thus open fires should always be built in the open air or in well ventilated rooms - since it releases CO and a number of organic volatiles. But even then cooking or heating by an open fire can be dangerous, smelly and dirty.

There are two ways to avoid most of these inconveniences:

1. Replacing open fires by a stove or hearth provided with a chimney which will remove all undersirable gases.

2. Use of charcoal.

Charcoal preparation involves partial burning of wood under controlled conditions of oxygen supply. This reduces the major part of carbon to its elementary state.

The gain is a smokeless solid fuel, having 20-30% of the dry weight of wood. The efficiency in burning charcoal especially for cooking in higher than for fuelwood, and considerable savings in energy can be made in transport. Charcoal has a highter calorific value per unit weight, so that a more concentrated fire and higher temperatures can be attained.

4. Ethanol

Ethanol can be used for cooking and lighting. A variety of simple stoves are available for use with alcohols. The flame is clean, smokeless, odourless, easily controlled and readily ignited and extinguished. Ethanol can also be used for transportation and power generation.

Ethanol can be prepared from cellulose (wood chips), starch and sugar containing raw materials.

2. COWDUNG CAKES

In rural India dung cakes are used as cooking fuel. When the dung is used to cook food, there is less fertiliser to grow food for the next season.

Women in India who cook food by burning biomass fuels like wood or cowdung expose themselves to high levels of pollutants including a deadly chemical, benzo-a-pyrene, which is suspected to cause cancer.

Above problems can be solved if the dung is used to generate biogas.

3. BIOGAS (GOBAR GAS)

Biogas is produced by the anaerobic fermentation of biomass. It consists of 50-70% methane, 30-40% CO_2, 1% H_2S and traces of bydrogen, oxygen, nitrogen and carbon monoxide.

Biogas has an approximate calorific value of 5500—6500 kcal/m^3 (23-28 MJ/m^3) as compared to 8500-9500 for methane. In more concrete terms, 1 m^3 gas keeps a gas lamp equivalent to 60 W burning for 6—7 hours, or cooks 3 meals for a family of 6.

Waste Materials for Biogas — Waste biomass for the production of biomass includes night soil, agricultural residues, garbage, industrial wastes and durg. About 30% of the population in the developing countries uses durg and crop residues as fuel to cook food. Thus valuable manure to be used to raise food crops is burnt. This problem can be solved by using dung and agricultural residues to generate biogas (gobar gas).

Table 53·1 : *Annual production of waste in India*

Cattle	1225.0 Mt
Buffalo	437.0 Mt
Goat and Sheep	28.0 Mt.
Night Soil	304.0 Mt.
City refuse	15.0 Mt.
Other Wastes	23.0 Mt.
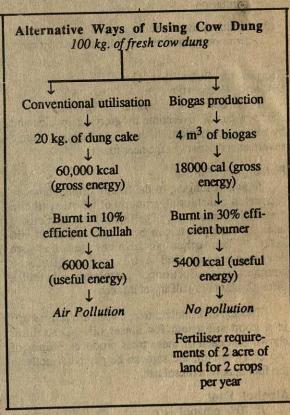
Anaerobic fermentation of dung yields fuel as well as fertilizer. Energy yield of biogas is lower than that of dung cakes, but efficiency of biogas burner is higher than that of chullahs and is more cost effective.

Production of Biogas.— The degradation process to produce biogas from biomass wastes takes place in three stages, during which numerous different types of organisms are engaged :

(i) **Facultative–anaerotic microorganisms** break down the polymers such as fats (lipids), proteins, cellulose and hemicellulose. Apart from producing simpler soluble compounds, this removes oxygen from the closed environment, an important step for the subsequent methanization process.

(ii) **Acid**–forming bacteria turn the compounds formed in phase (*i*) into organic acids, such as acetic acid, proprionic acid and lactic acid.

(iii) **Methogenic bacteria**, which harvest preferably on acetic acid, form CH_4. In the presence of hydrogen they can also reduce CO_2 to CH_4.

The net result of these three concurrent microbial conversion processes in the production of microbial biomass to be used as fertiliser and biogas. Generally, cellulose digestion is the more time consuming step.

Biogas production has been taken up on a large scale in India. A few thousand community biogas plants and over a million individual biogas plants are already in operation.

Alternative Ways of Using Cow Dung
100 kg. of fresh cow dung

Conventional utilisation	Biogas production
↓	↓
20 kg. of dung cake	4 m³ of biogas
↓	↓
60,000 kcal (gross energy)	18000 cal (gross energy)
↓	↓
Burnt in 10% efficient Chullah	Burnt in 30% efficient burner
↓	↓
6000 kcal (useful energy)	5400 kcal (useful energy)
↓	↓
Air Pollution	*No pollution*
	Fertiliser requirements of 2 acre of land for 2 crops per year

Advantages of Biogas

(1) At village level it provides the family with a clean energy source for cooking and lighting.

(2) It is a storable source of energy and has wider applications than the traditional energy sources.

(3) It results in the production of microbial residue to be used as fertiliser.

(4) Reduces faecal pathogens and improves sanitation.

(5) Reduces the chances of transfer of pathogens from one year's crop residue to the next crop.

Biogas as Substitute for Oil and Petroleum

Fuelwood is a renewable energy source. Its shortage can be overcome by growing species and by biogas production. Man will be facing the most severe energy crises in the near future.

Petroleum Plants

Plants belonging to the family *Euphorbiaceae* convert a substantial amount of photosynthetic metabolites into *latex*. The liquid hydrocarbons in latex of such plants can be substituted for liquid fuels. The other such plant families are *Asclepiadaceae* and *Apocynaceae*. But the commercial production of petroleum substitutes through plants is still in its infancy.

The sap of Brazilian tree, *Cobaifera langsdorfii* is a good substitute for diesel oil. Tests have shown that each of these trees produces 3 litres of sap every month; the sap can be placed directly in the fuel tank of a diesel car.

Alcohol Fuel

If 10% ethanol is mixed with 90% petrol, a motor fuel called *gasohol* is produced. During World Wars I & II ethanol powered vehicles were common in Europe. It has been used in many other countries as motor fuel. The existing engines need to be modified to use *gasohol* and *ethanol*.

Raising of crops like maize, potato, sugarcane, sugarbeet and tapioca for the production of alcohol is known as *energy cropping*.

The production of ethanol for the fuel has increased dramatically in recent years. Today, the largest producer of ethanol fuel is Brazil which distilled about 5 billion litres of this fuel in 1986.

Table 53·2: Alcohol production by energy cropping

Crop	Average yield (Tonnes/ha)	Alcohol production (Litres/tonne)	(Litres/ha)
Potato	15.0	110	1650
Maize	3.5	350	1225
Sugarbeet	20.0	90	1800
Sugarcane	55.0	70	4000
Mollases	2.5	565	60
Tapioca	16.5	3000	250

Following substances can be used for biogas production —

1. **Animal wastes** — Cattle dung and urine, slaughter house waste (blood, intestine, etc.), sheep and goat waste and fishery waste.

2. **Crop residues** — Crop stubble, straw, wasted fodder, cotton and jute sticks and weeds.

3. **Forest residues** — Leaves litter, bark, twigs, branches and undergrowth.

4. **Human wastes** — Night soil *i.e.* faeces and urine.

5. **Waste and by-products from Agro-industries** — Wastes from fruits and vegetables, bagasse, bran, tobacco and wastes, oil cakes, tea and coffee wastes.

6. **Aquatic plants** — Water hyacinth, algae and sea weeds.

7. **Urban refuge** — Paper wastes, household residues and garbage.

QUESTIONS

1. What is bioenergy? Describe its various sources.

2. Can we do without animal energy? Give reasons for your answers.

3. Describe biofuels. Can they solve the energy problem?

4. Describe method to obtain energy for biofuels.

5. Enumerate the advantages of wood as a fuel.

6. Give characteristics of firewood. Mention two plants which are sources of good firewood.

7. Describe the concept of energy plantations.

8. What is meant by social forestry? What are its advantages in terms of energy supply ?

9. What is gobar gas? How it is produced and what are its advantages ?

10. What are petroleum plants?

11. Describe the concept of ethanol to be used as fuel.

12. What is energy cropping?

13. Match the terms in column I and with phrases in column II:

Column I	Column II
(i) Animal energy	A. source of liquid hydrocarbon
(ii) Latex	B. from dung produced
(iii) Biogas	C. used by everybody
(iv) Ethanol	D. from energy of plantations
	E. used as gasohol

14. Mark the following statements true (T) or false (F) and write the false statements in correct form,-
    (i) Wood, charcoal, coal, biogas and natural gas are sources of bioenergy.
    (ii) During the production of biogas cellulose, hemicellulose, starch, lignin and protein are hydrolysed.
    (iii) Biogas consists of carbon monoxide, methane and hydrogen.
    (iv) Wood can be converted into a number of different biofuels.

15. Match the terms in column I with the phrases in column II:

Column I	Column II
(i) Fuel wood	A. DAP
(ii) Methane	B. energy plantation
(iii) Ethanol	C. Wood gasification
(iv) Producer gas	D. Biogas production
	E. energy cropping

□ □

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Biotechnology

HISTORY

Biotechnology includes all those industrial processes that are mediated by living organisms or the substances produced by them. The process of fermentation with the aid of enzymes made by microorganisms, formation of yoghurt and cheese etc. are known for long.

History of biotechnology is associated with human cultural history. *Fermentation* was the first biotechnological process known to ancient people, who prepared alcohol by prolonged soaking of grains or by storing juices of fruits and palms. Now-a-days biotechnology provides a wide variety of products in very large quantities, some of which were previously prepared at home in small amounts and some of them are also being prepared daily at home.

Recent advances in last two decades both in microbiology, molecular biology and genetic engineering have opened up new areas where microbes can be exploited for production of industrially important biochemicals, such as yeast, alcohol, enzymes, antibiotics, vaccines, growth hormones amino acids, citric acid, gluconic acid, lactic acid as well as some food materials.

Industrial revolution in the field of biotechnology has led to the establishment of a number of biotechnology companies, such as: *Genemtech Inc.* (USA), *Cetus Corp.* (USA), *Hybritech* (USA), and *Biogen* (Switzerland, USA). Nobel laureates, *Glaser* and *Gilbert* and many other eminent scientists are associated with these companies. Presently, gene technology or genetic engineering is the base of biotechnological research.

In India *National Biotechnology Board* (NBTB) was established in 1983 under the Department of Science and Technology. At present the following Biotechnology Centres are functioning in India:

(i) *Indian Agricultural Research Institute* (IARI), New Delhi;

(ii) *National Diary Research Institute* (NDRI), Karnal;

(iii) *Indian Veterinary Research Institute* (IVRI), Izatnagar (U.P.).

In addition, there is *International Centre for Genetic Engineering and Biotechnology* (ICGEB).

Application of Biotechnology

It involves production of following substances on commercial scale:

1. Enzymes, 2. Hormones, 3. Pharmaceuticals, 4. Antibiotics, 5. Antibodies, 6. Interferons, 7. Vaccines, 8. DNA probes, 9. Alcohol, 10. Proteins, 11. Polysaccharides, 12. Organic acids, 13. Biosolvents and 14. Biodetergents.

Industrial Uses of Micro-organisms

A number of micro-organisms are used in industry to convert readily available, and cheap raw materials into useful products. The microbes employed for industrial purposes include bacteria, yeasts and certain fungi. For economical use of micro-organisms in industry, following conditions are essential:

1. The micro-organism should be able to grow vigorously and has the capacity to produce industrial product in appreciable amount.
2. The medium or the raw material to be converted by the microbe should be cheap and readily available, preferably the waste products of one industry should form the raw materials for microbial processes.
3. The product must be easily recoverable in appreciable amounts.

The main use of microbes are in (a) certain food products such as cheese and bread, (b) fermentation leading to the production of alcohol, organic acids and certain chemicals and (c) production of antibiotics.

A. Use of Micro-organism in Food Products

1. Cheese

Cheese is made from the milk. There are two major groups of cheese: (1) the unripened cheese and (2) the ripened cheese. The soft cheese is ripened from outside only whereas the ripened cheese is ripened internally. The manufacture of cheese consists of the following steps:

1. A culture of lactic acid bacteria, Streptococcus lactis or S. cremoris, is added to the milk warmed at 38°C. For higher temperature of milk, culture of S. thermophilus mixed with Lactonacillus lactis, L. bulgaricus or L. helveticus is used.
2. When a certain acidity is reached by the activity of the bacteria, rennet is added. Rennet is an extract obtained from the calve's stomach. It contains an enzyme rennin, which coagulates caesin of milk and curd is formed.
3. The curd is removed and the liquid that separates out is called the whey. The whey contains 93% water, and the remaining 70% lactose, mineral salts, and other substances. It is used for the manufacture of lactic acid.

   The cheese, at this stage, has a rubbery consistency and sweetish in taste. If cheese is used at this unripened stage, it is called the cottage cheese.
4. Salting is the next step. Salt is applied to the cottage cheese and kept into frames and pressed. Salting serves two purposes—(1) It hastens the removal of moisture and (2) it prevents the growth of undesirable micro-organisms. The frames are removed as soon as the cheese sets.
5. Ripening of the curd to form cheese is carried in a special room kept at suitable temperature and humidity. The fermenting micro-organisms, which vary according to the variety of the cheese to be manufactured, are added to obtain cheese of desired flavour. The cheese is very nutritious as it contains 20 – 35% protein, 20 – 30% fat and a small quantity of minerals.

2. Buttermilk and Yogurt

Buttermiik or fermented milk is prepared by growing various types of lactic acid bacteria. For preparing buttermilk, a starch culture of Streptococcus cremoris, S. lactis and Leuconostoc citrovorum or L. dextranum is used. L. dextranum produces volatile acids and certain neutral products which give the buttermilk its typical flavour.

Yogurt is prepared by fermenting concentrated milk with a mixture of Streptococcus thermophilus and Lactonacillus bulgaricus at a temperature of 40—46°C.

Buttermilk and yogurt are very popular in western countries, where these are commercially produced and sold at groceries, whereas in our country these products are normally made at home.

3. Bread-making

The use of yeast in breadmaking was known to the Jews, Greeves and Romans during the ancient time. The old method of break making is still in use today with little modification.

Selected strains of Saccharomyces cerevisiae are mixed in the dough and kept at a temperature of about 25 to 26°C maintained under aerated conditions. As a consequence of fermentation, carbon dioxide is produced which causes leavening of bread imparting a desired flavour and change in the texture. The leavened dough is pressed into cakes and baked.

4. Food yeast

Yeast, because of its nourishing value, is taken as food supplement. It is a good source of vitamin B and contains 40 – 50 per cent proteins of its dry weight. The main source of dry yeast for food are the waste products of brewing industry.

Yeast is cultured in a medium containing molasses, cane sugar, potatoes or other fermentable carbohydrates. The waste sulphite liquor from paper and pulp manufacture which contains carbohydrates other than cellulose also forms a suitable medium for the culture of yeast species. Japanese have developed a new method of growing yeast in moist soft coke powder obtained as a waste from coal industry. The yeast cells which form a thick layer on coke powder are collected, pressed into cakes and dried.

Toroulopsis utilis, which is used as a rich food for man and animals, is cultured on molasses, cane

sugar juice, starchy materials and in sulphite waste liquor in the presence of ammonium sulphate till maximum crop is obtained. It is now collected, washed, dried and then marketed.

B. Use of Micro-organisms in Beverages
1. Alcoholic Beverages

Alcoholic beverages are obtained by making use of fermentation activity of different strains of *Saccharomyces cerevisiae*. Different carbohydrate sources are used to obtain beverages of desired flavours, *e.g.* beer is obtained from barley malt,

wine from grapes, rum from molasses, whisky from cooked grain mash saccharified with pealed malt, etc.

Besides alcoholic beverages, ethyl alcohol is also manufactured by employing any fermentable carbohydrate. When starch is used as a source of carbohydrate, it is first hydrolyzed to simple sugars. This is accomplished by barley malt, heat treatment of acidified medium or by certain fungi (mounlds rich in amylases). The scheme for the manufacture of alcohol is depicted in Figure 54.1.
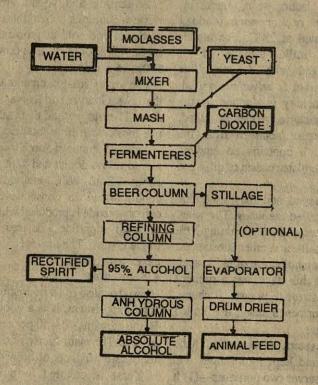
FIG. 54.1 Simplified flowsheet for the manufacture of alcohol from molasses by the activity of yeast.

The biochemical reaction is as follows:

$$C_6H_{12}O_6 \xrightarrow{\text{yeast}} 2C_2H_5OH + 2CO_2$$

Glucose, enzymes → Ethanol, Carbon dioxide

2. Vinegar

Vinegar is made by the fermentation of sugar or starchy material in two steps. First step involves the conversion of sugary or starchy material into alcohol by yeast fermentation. The second step

involves the aerobic oxidation of alcohol to acetic acid by acetic acid bacteria (*Acetobacter aceti*).

Vinegar fermentation is allowed to proceed till maximum strength is reached. Aging takes place during storage. With the formation of esters, the harsh flavour of vinegar disappears. Vinegar is used as a condiment, for preserving pickles, fruits and canned vegetables. It is also beneficial in digestion and in cases of constipation.

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C. Synthesis of Organic Chemicals and Enzymes

1. Organic Acid

Organic acids such as lactic acid, acetic acid, citric acid, gluconic acid etc. are produced industrially by micro-organisms. Some of these acids, their fermentation processes and applications are given in the table below:

2. Vitamins and Vitamin Precursors—Vitamins are important commercial sources of several vitamins. Some of them are given in table 54.1

(i) **Riboflavin (Vitamin B$_2$)**—It is a bitter, odourless, crystalline, yellow-orange powder in its pure form. It is essential for growth and reproduction in human beings.

Riboflavin is produced by a number of micro-organisms, such as yeasts, *Ashbys gossypi*, *Eremothecium ashbyii*, and certain bacteria. Commercially it is obtained by culturing *A. gosypii*, *E. ashbyii*, *Closteridium butyricum* and *Cl. acetobutylicum*. After culturing, it is obtained from the substrate by solvent extraction with butanol, or by adsorption on Fuller's earth or silica gel.

(ii) **Vitamin B$_{12}$ or Cobalmine**—It is a water soluble vitamin used for treating anemia and increasing appetite in man. It is also used to supplement animal feed

Vitamin B$_{12}$ is commercially obtained by growing *Streptomyces olivaceus* (actinomycetes) and *Bacillus megatherium* (bacteria) in a nutritive medium containing starch, sugarcane molasses corn sugar or corn syrup. After maximal growth, the cells are collected by centrifugation filtration or decantation to be used as animal feed supplement with or without drying. For medical purposes, the pure vitamin is obtained by autolysing the cells in water at 100°C. The vitamin being soluble in water, is liberated into the aqueous phase from where it is concentrated and purified.

(iii) **Vitamin C or Ascorbic acid**—It is manufactured from its precursor, L-Sorbose which is commercially produced from D-Sorbitol by biological dehydrogenation. The conversion is brought about by various species of *Acetobacter*. The flow chart for the manufacture of vitamin C (ascorbic acid) from L-Sorbose is given in Fig. 54.2.

Enzymes

Many microbes are the source of various enzymes which have wide industrial application. Some of these enzymes which are of industrial importance are given in Table 54.2.

Dextran

Dextrans are medically of great significance as they are used in blood plasma transfusions. Swedish were the first people who made use of dextrans for transfusions during World War II.

Dextrans are polymers of D-glucose and also are polyglucosans. These may be produced by the fermentation process or by the use of enzyme dextran sucrase which is also obtained commercially from micro-organisms. By enzymatic process, a good amount of dextran of molecular weight suitable for clinical use is obtained. Industrially, *Leuconostoc mesenteroides* is used for the production of dextrans of suitable molecular weight.

$$\text{Sucrose} \xrightarrow[\text{enzymes}]{L.\ mesenteroides} \text{Dextran + Fructose}$$

Steroids

Steroids are complex organic compounds which have a wide range of biological activities. These include cholesterol and other steroids, the bile acids of bile juice, the male harmone-testosterone, and female hormones—progesterone and oesterogen, and the hormones of the adrenal cortex.

The steroids are manufactured by a combination of chemical and microbiological methods. Progesterone can be converted to various other steroids, the nature of product being determined by the type of micro-organisms used as shown in Fig. 54.3.

The steriods are finding wide use in family planning and in the treatment of certain chronic diseases. Progesterone is produced by the corpus luteum of the ovary at the time of ovulation and is responsible for the changes taking place during the latter half of the menstrual cycle. Cortisone and other related corticosteroids regulate carbohydrate and protein metabolism. These make glycogon to accumulate in the liver, induce marked decline in circulating lymphocytes and ecosinophilic leucocytes, and degeneration of the thymus gland. These are also responsible for inhibiting the inflammatory response.

D. Synthesis of Antibiotics

An antibiotic is a metabolic product of one micro-organism which is harmful to other micro-organisms. It is interesting to note that the activities

Acids	Organism	Raw Materials	Application
1. Lactic acid	*Lacto-bacillus delbruck, L. bulgaricus,* and *Streptococcus lactis.*	Acid hydrolyzed, corn starch or ptotatoes, whey molasses, waste sulphite liquor, plus nutrients according to the organisms used.	Edible grade of lactic acid is used in confectionary extracts, fruits juices, essences, lemonades, pickles, curing of meat, in canned vegetables and fish products, where it acts as a preservative. It is also used in the making of effervescent beverages, in dyeing of silks and other textile goods, a mordant in printing of woollen, in leather industry for deliming of hides and vegetables tanning, as flux for solder and in plastic industry. Salts of lactic acid also have wide utility.
2. Acetic acid	*Acetobacter sp.*	Fruits, sugar containing syrups, hydrolyzed starchy material.	Vinegar and other industrial uses of acetic acid.
3. Citric acid	*Aspergillus niger*	Sugar	(i) Medicine, (ii) flavouring extracts, (iii) foods and candies (iv) manufacture of ink, (v) dyeing and (vi) engraving.
4. Gluconic acid	*A. niger, Pencillium purpurogenum* and *P. chrysogenin.*		(i) Pharmaceuticals, (ii) calcium gluconate is used as a source of calcium in feeding infants and pregnant women, and for treatment of milk-fever in high producing dairy cows.
5. 2-keto-gluconic acid	*Pseudomonas sp.*	Glucose, gluconic acid.	Intermediate for D-araboascorbic acid.
6. 5-keto-gluconic acid	*Acetobacter suboxydans*	Glucose	Intermediate for tartaric acid.

Table 54.2 : Microbial enzymes and their applications

Enzyme	Organism	Application
1. Amylases	*Bacilus subtilis, B. maceranus, Polymya, Aspergillus niger, A. oryzae, Rhizopus oryzae.*	(i) Liquefaction and saccharification of starch, (ii) reduction of viscosity of chocolate syrups, (iii) clarification of turbidity of fruit juices caused by starch, (iv) sizing of paper, (v) sizing and desizing of textiles.
α		
β-*amylase*	*B. subtilis*	(i) Production of corn syrup, (ii) modification of dough in baking industry, (iii) correction of deficiencies in digestive enzymes.
2. Cytase	—	—
3. Cellulose	*Myrothecium verrucaria.*	*Production of dextran; production of fructose.*
4. Dextran-sucrase	*Leuconostoc meseniteroides.*	Removal of oxygen in presence of glucose; removal of glucose from food products (*e.g.,* eggs before drying).
5. Glucose oxidase (yellow enzyme)	*P. notatum*	Production of soft centres in candy.
6. Invertase	*Saccharomyces cere visiae, S. exiguus*	Prevention of sandiness in dairy products such as ice-cream, processed cheese, etc.
7. Lactase	*S. fragilis, Torula cremori.*	Making cheese from pasteurized milk.
8. Lipase	*Candida lipolytica. A. lucherisis.*	(i) Clarification of fruit juice and enzymes, (ii) preparation of green coffee, (iii) acceleration of filtration of fruit products, and (iv) retting of flax for linen production.
9. Pectinases	*Byssochlamys fulvo*	Destruction of antibiotic action of pencillin.
10. Penzillinase	*B. brevis, Actinomyces candidus*	—
11. Protease	*Mortierella renispora*	(i) Liquefaction and hydrolysis of casein, lactalbume, gelatin and other proteins, (ii) destruction of gelatin sizes, (iii) chill-proofing of beer, (iv) unhairing of soaked hides; (v) removal of stains, (vi) manufacture of liquid glue, and (vii) degumming of silks.

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┌─────────────────────┐
│   TUBE CULTURES     │
│   OF ORGANISMS      │
└─────────────────────┘
          │
          ▼ TO INOCULATE
┌─────────────────────┐
│ 800 ML              │
│ MEDIA CONTAINING    │
│ 10% SORBIOTOL, 0.5 YEAST │
│ EXTRACT AERATION 48 HRS │
└─────────────────────┘
          │
          ▼ TO INOCULATE
┌─────────────────────┐
│ 2.5 LITRES          │
│ NUTRIENT SOLUTION   │
│ CONTAINING SORBITOL │
│ YEAST EXTRACT, GLUCOSE │
│ AND CALCIUM CARBONATE │
│ IN DRUM FERMENTER   │
│ LIMITED AERATION AND │
│ AGITATION AT        │
│ ATMOSPHERIC PRESSURE │
│ FOR 24-48 HRS       │
└─────────────────────┘
          │
          ▼ TO INOCULATE
┌─────────────────────┐
│ 8 LITRES SORBIITOL  │
│ SOLUTION IN DRUM    │
│ FERMENTER           │
└─────────────────────┘
          │
          ▼ OXIDATION
┌─────────────────────┐
│ SORBOSE YIELDS      │
│ IN EXCESS OF 90%    │
│ IN 15 TO 32 HRS.    │
└─────────────────────┘
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Fig. 54.2 Production of L-Sorbose from sorbitol.

of antibiotics were known even before they were chemically isolated. Their discovery came into light when PASTEUR and JOUBERT observed that the *Anthrax bacilli* grow well in urine but disappear from it when certain other microbes are present. The old village-ladies still give a dose of urine of a child for his own cough or cold infection. Earlier, the Chinese used mouldy soyabean curd for the treatment of boils.

GRATIA and DATH (1924) successfully isolated 'Actinomycetin' from a filamentous fungi, the *Actinomycetes*. However, this compound was never used for the treatment of patients.

In 1929, ALEXANDER FLEMING observed that in some cultures of *Staphylococcus aureus*, a portion of the culture medium has luxuriant growth of some mould. There were clear zones between the areas where the bacteria and the mould grew. He further observed that as the mould grew, the bacteria in its vicinity were killed. FLEMING inferred that the mould produced something into the medium which had killing effect on the bacteria. This mould was identified as *Pencillium notatum* and the substance which killed the bacteria as 'pencillin'.

FLEMING continued his research and in February, 1941, gave his first injection to a dying man unaffected by other drugs. Amazingly, the patient showed immediate improvement but unfortunately for him only a teaspoonful could be prepared then which was too little to effect a radical cure. Soon some British and American pharmaceutical firms undertook to manufacture it on large scale.

Another antibiotic, called *streptomycin*, was isolated in 1944 by WAKSMAN from a species of soil-bacteria, called *Streptomyces grisesus; chlor-*
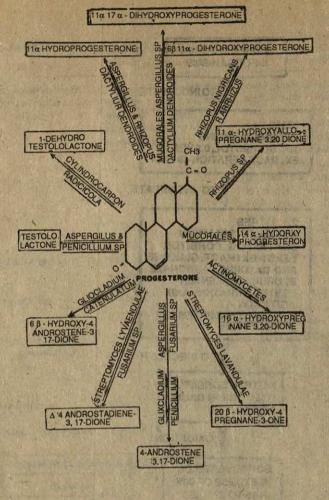
Fig. 54.3 Production of various steriods from progesterone by fundi and bacteria as a result of microbiological transformation

omycetin by BURKHOLDER in 1947 from *Streptomyces venezuelae*. Next in the chain of antibiotics was *aureomycin* in 1948 by DUGGAR from *Streptomyces aureofaciens* and *terramycin* in 1950 from *Streptomyces rimosus* and *Erythromycin* by McGUIRE in 1952 from *Streptomyces erythrenes*. Since then a large number of antibiotics have been discovered, many of which are in medical use. A list of the common ones along with the names of the organisms which produce these antibiotics and the organisms against which these are effective are given in Table 54.3.

Besides their use in the treatment of human diseases, certain antibiotics are used as food preservative, and for the treatment of animal feed. Some antibiotics are also used in tne control of plant pathogens. Griseofulvin, which is not suitable to man, is used in the control of bean rust. Tetracycline and streptomycin are also widely used. These are used as sprays or through the root. The antibiotics are also used in the preservation of food, fish and meat.

Methods of Antibiotics Production—The micro-organism, to be used for antibiotic production, is cultivated in a sterilized nutrient medium. This medium contains the sources of carbon, nitrogen, minerals and buffers. The precursors are added to increase the yield of the antibiotic. After inoculation with a suitable strain of microorganism, the medium is maintained at optimal pH and temperature. To allow the uniform growth of the microbe, the medium is constantly agitated and

S. No.	Antibiotics	Producing organisms	Sensitive organisms
1.	Pencillin	*Pencillium notatum*	Gram-positive bacteria; *Neisseria; Spirochaetes;* actinomycetes; Clostridia; *Corynebacterium diphtheriae.*
2.	Streptomycin	*Streptomyces griseus*	Gram-positive and gram-negative bacteria; Mycobacterium tuberculosis; Actinomycetes.
3.	Becitracin	*Bacillus licheniformis*	Gram-positive bacteria; *Histoplasma capsulatum.*
4.	Chloramycetin	*Streptomyces venezuelae*	Gram-positive and gram-negative bacteria; rickettsial and large viruses; *Endomoeba borrelia, Actinomyces boris.*
5.	Chlorotetracycline	*Streptomyces aurefaciens*	Gram-positive; and gram-negative bacteria; rickettsial and large viruses.
6.	Tetracycline	Catalytic hydrogenation of chlortetracyline	Klebsiella pneumoniae; Type A— *Streptococcus nitis; Salmonel typhose, Pasturella multocida;* some staphylococci.
7.	Erythromycin	*Streptomyces erytheraeus*	Gram-positive bacteria; some gram-negative bacteria; rickettsial and large viruses.

or mycelium by filtration or centrifugation, and the second involves the removal of the antibiotic from the medium by solvent extraction, absorption or precipitation.

Purification of Antibiotic—The antibiotic so obtained is made pyrogenated by filtering through bacterial filters of suitable nature. The potency of the product is bioassayed, using standards for comparison.

Role of Microbes in Elimination of Undesirable Materials

The saprophytic bacteria bring about the decomposition of dead organic matter. During the process the carbon, hydrogen, nitrogen, phosphorus, sulphur, etc. which form the important constitutents of plants and animal bodies, are reduced to simple compounds such as carbon dioxide, sulphates, nitrates, phosphates, water, etc. These compounds return to the soil and air from where they are again used as raw materials for food synthesis. The breakdown of nitrogenous organic compounds takes place in the absence of air and is known as *purification* while the decomposition of other organic compounds taking place in the presence of oxygen is termed as *decay*. Thus the bacteria of decay and decomposition function as Nature's scavangers by removing the harmful waste from the surface of earth.

The disposal of waste sulphite liquor from paper and pulp industries into natural streams and rivers endangers aquatic life and makes water unsuitable for drinking purposes. Torula yeast (*Torulopsis utilis*) makes use of this cheap and easily available medium and converts the wastes into proteins and vitamins in easily consumable state.

Similarly, waste materials such as wood shavings, saw dust, straw, corn cobs and other agricultural wastes are used for raising yeast for animal feed. *Lactobacillus delbruecki, L. bulgaricus* and *Streptococcus lactis* produce lactic acid from waste materials such as whey, molasses and waste sulphite liquor. Molasses is also acted upon by different strains of yeast to give rise alcoholic beverages.

The industrial wastes of several other industries which pollute water are decomposed into non-toxic substances by microbes. Phenolic wastes and disposed material containing formaldehyde are rendered harmless by the oxidative ability of different species of *Nitrosomonas*. Chemicals like DDT, etc. in low concentration are also degraded by the bacteria and other microbes.

Scaling Up Laboratory Finding to Industrial Production

Most industrial technologies are based on research findings made in a laboratory. These have to be gradually scaled up to industrial level. Development of process for commercial production is

the result of combined efforts of several special- ists like engineers, production managers and work- ers.

In the laboratory, the suitable environmental conditions for growth such as sterilized growth medium, nutrients, required pH, temperature, oxygen etc. can easily be maintained. The micro- organisms grow in small glass fermenters. At the industrial level, manufacturing is done at a very high level. The flasks are replaced by large stain- less steel growth vessels. The *bioreactors* are designed to provide required pH, temperature and to prevent foaming and damage to the micro- organism cells.

Micro-organisms are then introduced in the bio- reactors where these can be grown by one of the two methods:

1. The micro-organisms form a thin layer or film on the surface of nutrient medium (*Support Growth System*).

2. Micro-organisms form suspending cells in the growth or nutritive medium (*Suspended Growth System*).

ROLE OF GENETIC ENGINEERING AND TISSUE CULTURE

Genetic engineering or recombinant DNA technology has enabled the commercial production of *hormones, enzymes, interferons, immunogenic substances* and *vaccines* for theraptic applications.

1. Biosynthesis of human insulin—Biotechno- logically synthesized human insulin in colon bacilli, *E. coli* is named *humulin*. The process involves following steps:

(i) RNA for synthesis of insulin is extracted from specialized animal cells (β-cells of Islets).

(ii) By the enzyme *reverse transcriptase* single strand of DNA complementary to *m*RNA is synthesized.

(iii) Second strand of DNA complementary to first strand is synthesized by enzyme DNA *polymerase.*

(iv) Double stranded *copy DNA* is joined to a plasmid by using enzyme *terminal*

transferase.

(v) The ends of two DNA, is annealed by enzyme *ligase.* Thus the ends of inserted DNA and plasmid DNA are sealed and a new circular plasmid is formed. This is a molecule of *recombinant DNA.*

(vi) This recombinant DNA molecule is inoculated in new bacterial cell of *E. coli* and inserted in the bacterial gene after having cut it by a restriction enzyme.

Insulin is formed of two polypeptide chains A and B, composed of 20 and 30 amino acids respectively. The sequence of amino acids in insulin was worked out by SANGER. The synthesis of both chains and their linkage by disulphide bonds was worked out in 1963 and 1965.

2. Biosynthesis of Somatostatin—Human growth hormone (hGH) or *somatotropin* is secreted by anterior lobe of pituitary. It was isolated and purified in 1963 by ROSS and his coworkers. Its deficiency results in dwarfism. The harmone is species-specific. It consists of 191 amino acid units.

Biosynthesis of somatotropin was carried out by GOEDDEL and his coworkers at Genetech. The cDNA for human growth hormone somatostatin was inserted by pBR_{322} plasmid in *E. coli* chromosome close to the gene that codes for enzyme β-galactosidase.

3. Production of interferon—Application of genetic recombination to the production of biologically active substances for the treatment of genetic diseases or genetic anamolies is the field of current and future biochemical research.
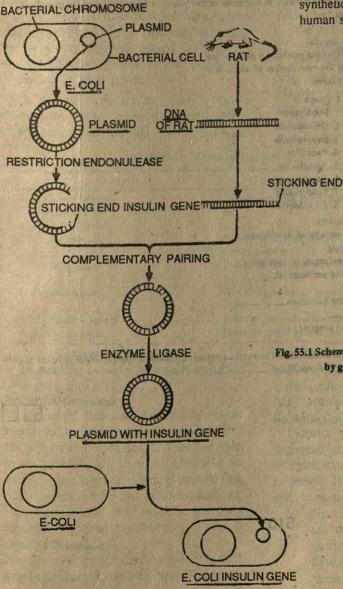
Interferon are proteins released in minute quantities by animals and even human cells on being infected by virus. These form the first line of defence against viral infection. Interferon can help to cure viral diseases such as *common cold, hepatitis* and *herpes zoster.* It boosts immunity and inhibits multiplication of abnormal cancer cells.

Interferon are species specific and interferon from one animal cannot be used to treat human patients. The common human interferons are—

(i) *Leucocytic interferon*—α

(ii) *Fibroblastic interferon*—β

(iii) *Immune interferon*—γ

The basic process of interferon production is the same. It involves maintenance of cell culture of somatic cells or transformed leucocytes (*i.e.* lymphoblastoid cells) and then the infection of these cells with Sendai virus. After 24 hours of infection they are centrifuged and crude interferon is extracted from the supernatant and purified.

Genetic recombination of interferon gene in cells of colon bacteria or yeast is another method of inerferon synthesis.

4. Production of Immunogenic Substances and Vaccines—Another area of application of genetic engineering or recombinant DNA technique is production of new effective, safe and low-cost vaccines. In May 1980, a French team induced genetically engineered bacteria and mouse cells to produce protein of *hepatitis-B virus* that confers immunity against this virus. Preparations of vaccines against dephtheria, poliop, etc. are also being tried.

The production of hormones, enzymes, etc. by recombinant DNA technology will reduce the immunogenic intolerance occasionally found with synthetic peptides or peptide isolates from non-human sources.

Fig. 55.1 Schematic representation of biosynthesis of rat insulin by genetically engineered colon bacteria.

QUESTIONS

1. Describe the general properties of antibiotics which make them suitable for medicine.
2. Write a short eassy on "yeast in food and beverage industry".
3. Describe the uses of micro-organisms in the processing of milk-products.
4. Microbes help us in utilizing the waste products of industry. Justify this statement.
5. Name the micro-organisms associated in the manufacture of (1) vinegar, (2) alcohol, (3) tetracycline, (4) citric acid.
6. Write short notes on the manufacture and uses of (a) yoghurt, (b) dextran, and (c) steroids.
7. What is an antibiotic ? Write a note on the discovery of penicillin.
8. List the properties of an antibiotic which can be used as a medicine for human diseases.
9. Write notes on the following:
   (a) Organic acid fermentation
   (b) Commercial production of dextran.
10. What is the advantage of steroids or their derivatives in the daily life of human beings ?
11. Write an account of food products obtained as a result of icrobial activity.
12. What is the significance of micro-organisms in the elimination of undesirable materials?
13. Mention the role of yeasts in bread industry. Is it possible to use some of the yeasts as food for direct consumption?
14. Name the micro-organism which is taken as food.
15. What is the cause of leavening of dough?
16. Why wine becomes sour when left open in the air?
17. Name a micro-organism employed in the industrial production of enzymes.
18. Name any two micro-organisms involved in the manufacture of acetic acid.
19. Match the items of column A with those in column B:

Column A	Column B
(a) Dextran	1. Food yeast
(b) Vinegar	2. Griscofulvin
(c) *Torulopsis*	3. *Streptomycin*
(d) Antifunfal antibiotic	4. *Penicillin*
(e) Curd	5. *Acetobacter*
(f) Cheese	6. *Saccharomyces*
(g) Waksman	7. *Leuconostoc*
(h) Invertase	8. *Lactobacillus*

20. Say 'true' or 'false' for the following statements:
    (a) Vinegar is the product of fermentation activity of *Acetobacter*.
    (b) Penicillin is used as an antifungal antibiotic.
    (c) *Streptomyces griseus* is used in the manufacture of tetracyclin.
    (d) Both streptomycin and chloromycetin are antibacterial.
21. Fill in the blanks in the following:
    (a) Vinegar is a fermentations product of the bacterium...................
    (b) Pencillin was first isolated by......................
    (c) Lipase is commercially produced by the fungus......................
    (d) The yeast directly used as food is..................
    (e) ....is an organic compound which can be transformed into various steroids depending on the activity of different microbes. .
    (f) One of the industries dependent on fungus *Penicillin* is ....

Human Diseases

Human Disease

The most important contribution of science towards human welfare is the knowledge of various human diseases and their remedy. It has alleviated human pain and suffering beyond measure and has opened up new vistas of health and longevity.

What is a Disease

Disease is not easy to define. It can be described as a condition of the body or a part of it which reflects some disturbance or derangement of its function or functions. It can be defined as a disorde in the physical, physiological, psychological or any other function of the body caused either due to nutritional deficiency, genetic disorder, pathogenic invasion or any other reason.

Most diseases are accompanied by *signs* and *symptoms* which make the person suffering and also the doctor aware of not being well.

be communicable or noncommunical depending upon the nature and cause of the disease.

(A) Infectious or Communicable Diseases

The communicable diseases such as common cold, influenza measals, plague, pneumonia typhoid, tuberculosis, malaria and amoebiasis etc. are caused by the presence of some parasities in the human body such as viruses, bacteria, fungi, protozoa and worms. These disease producing organisms are called *pathogenic organisms* and man is called the *host*.

The pathogenic organism in the body of host

DISEASE CAUSING AGENTS

Any substance or force whose presence in excess or in relatively low quantity causes a disease is a *disease causing agent*. These agents may be— grows and multiplies and produces disease either by destroying host tissue or by producing poisons, the *toxins*. These disease producing organisms

Table 55.1 Disease causing Agents

Category	Agents
1. **Biological Agents** (Pathogens)	Viruses, bacteria, fungi, mycoplasma, protozoans, helminths etc.
2. **Chemical agents**	
(i) Endogenous	Urea, uric acid, glucose, hormones, enzymes, cholesterol, smoking, tobacco.
(ii) Exogenous	Pollutants, industrial wastes, insecticides, spores, pollens, fertilizers etc.
3. **Physical agents**	Heat, cold, humidity, pressure, radiation, electricity and sound etc.
4. **Mechanical agents**	Fractures, sprains, dislocations, trauma, and chronic frictions.
5. **Nutrient agents**	Minerals, carbohydrates, proteins, fats and vitamins.

TYPES OF DISEASES

All human diseases can be broadly classified into two categories—

1. Congenital Diseases

The congenital diseases are caused by genetic disorders (*i.e.*, abnormal genes or abnormal number or structure of chromosomes) and are heritable. These are present right from the birth and are expressed in the form of errors in metabolism, (*phenylketoneura, sickle cell anaemia, diabetes, mellitus, haemophilia* etc.) or defective body development or mental retardation.

2. Acquired Diseases

These diseases are acquired by the individual any time in its life cycle but after birth. These may

enter the new individuals either directly by contact or by contaminated air, water or food or by some carrier, called *vector*

(B) Noncommunicable Diseases or Noninfectious Diseases

Diseases other than infectious ones such as degenerative diseases, deficiency diseases, allergies, cancers etc. do not spread from person to person. Hence, these diseases are known as *noncommunicable diseases* or *noninfectious*.

(i) *Nutritional Deficiency Diseases*—These are caused by the deficiency of some nutrient in the diet, like deficiency of protein, carbohydrates, vitamins and minerals.

(ii) *Allergies and inflammations*—These are caused by the hypersensitivity of the body to foreign substances, like pollen grains, dust, silk, nylon, certain drugs, volatile substances in the atmosphere.

(iii) *Degenerated Diseases*—These are caused by the malfunctioning of some vital organ/organs of the body like lungs, heart and central nervous system. For example,

Table 55.2 Summary of Various Human Diseases

Type	of	Disease	Example
Transmissible or Communicable			
1. Diseases caused by micro organisms :- viruses:			measles, rabies, poliomyelitis, small pox, typhus, yellow fever
	bacteria:		cholera, tuberculosis, whooping cough
	protozoa:		trypanosomiasis
		malaria,	foot
	fungi:	ringworm,	athlete's onchocarciasis
2. Diseases caused by larger organisms:- roundworms		ascariasis, ,	tapeworm
	flatworms	schistosomiasis,	
Non-transmissible or Non-Communicable			
1. Nutritional deficiency diseases:		beri-beri;	pellagra; kwashiorkar
			phenylketonuria
2. Metabolic disorders :		diabetes;	
3. Allergies and Inflammations			
4. Degenerative Diseases:		Coronary heart diseases;	arthritis
5. Inherited diseases		Sickle cell	anaemia
(i)		Disfuction Sickle cell	anaemia
(ii)	sex linked	Alcapthuaria;	phenylketonuria
(iii)	Genectic incompitability	Rh-factor; blood	groups
6.		Cancer	
7. Mental disorders		depression;	alcoholism
8. Occupational or industrial diseases (Toxicology)		silicosos.	

Table 55.3 Some widespread diseases and their consative agents

Diseases	Causative organism	Mode of Spread
(A) Viral Diseases		
Measles	virus	airborne droplet infection
Poliomyelitis	virus	contaminated water
Rabies	virus	bite of infected mammal
Smallpox	virus	airborne, droplet infection
Typhus (Relapsing fever)	virus	bite of infected louse or flea
Yellow fever	virus	bite of infected female *aedes* mosquito
(B) Bacterial Diseases		
Cerebro-spinal meningitis	bacterium (*Neisseria*)	airborne, droplet infection
Cholera	bacterium (*Vibrao chollerae*)	contaminated drinking water or food
Dysentary (bacillary)	bacterium (*Shigella*)	Contaminated drinking water or food
Leprosy (Hansen's disease)	bacterium (*Micobacterium leprae*)	airborne, droplet infection
Tetanus	bacterium (*Clostridium tetane*)	enters through breaks in skin
Tuberculosis	bacterium (*Mycobacterium tuberculosis*)	air borne, droplet infection
Typhoid	bacterium (*Salmonella*)	contaminated food and water
Whooping cough	bacterium (*Bordetella*)	airborne, droplet infection
(C) Fungal Diseases		
Ringworm	Fungus (*Trichophyton*)	skin contact
Tinea	Fungus (*Trychophyton*)	skin contact

Diseases	Causative organism	Mode of Spread
(D) Protozoan Diseases		
Dysentary (amoebic)	protozoon (**Entamoeba**)	contaminated drinking water
Malaria	protozoon (**species of Plasmodium**)	bite of infected female anopheline mosquito
(E) Diseases caused by Helminths		
Ascariasis	large nematode or roundworm (*Ascaris*)	eggs swallowed with food or water
Elephantiasis (filariasis)	nematode, filarial worm (*Wucheraria*)	biting of mosquitoes
Hookworm	nematode (*Ancylostoma, Necator*)	direct penetration through skin by larvae
Pin-worm	nematode (*Enterobius*)	anus-to-mouth
Schistosomiasis (Bilharzia)	blood fluke (*Schistosoma*)	direct penetration of skin by larvae or swallowed in water
Tapeworm	platyhelminth (species of *Taenia*)	eating raw or under cooked infected meat.
(F) Diseases caused by mites and fleas		
Jigger (Chigger)	flea (*Tunga*)	direct penetration of skin
Scabies	mite (*Sacroptes*)	direct penetration of skin by female mite.

Table 55.4 Some vaccines in common use

Purpose	Type of vaccine	Method of introduction
Vaccines for large-scale use:		
BCG (antituberculosis)	attenuated bacillus	injected
antitetanus	toxoid	injected
antipoliomyelitis: Sabin	attenuated virus	oral
Salk	killed virus	injected
antidiphtheria	toxoid	injected
antimeasles	attenuated virus	injected
anti whooping cough	killed bacteria	injected
Vaccines for use with persons who are exposed to particular risk		
Typhoid	killed bacteria	injected
yellow fever	attenuated virus	injected
meningitis	killed bacteria	injected
measles	attenuated virus	injected
rabies	attenuated virus	injected
cholera	killed bacteria	injected
Serum for use after a person has been exposed to infection:		
antirabies	both contain ready-made	injected
antitetanus	antibodies	injected

arterosclerosis, rheumatic heart, coronary heart.

- (iv) *Cancers*—The cancers are abnormal, uncontrolled and unwanted tumour-like growth of undifferentiated tissue in any part of the body.
- (v) *Mental disorders and smoking etc.*
- (vi) *Industrial diseases (toxicology) and pollution diseases.*

COMMUNICABLE DISEASES
(Infectious or Transmissible Diseases)

History

Communicable diseases are caused by *pathogens* which include microbes (viruses, bacteria), fungi, parasitic protozoa, helminth parasites and some arthropoids. The possible connection between living organisms and disease was speculated by FRACASTORIUS as early as 1546, who proposed that *Syphilis* is caused by **contagium vivam**—a live contact. LOUTS PASTEUR and ROBERT KOCH 1876-1885) established '*The germ Theory of Disease*'. Koch demonstrated rod-shaped bacteria in the blood of cattle that died of anthrax and showed that these bacteria could produce anthrax.

In 1884 KOCH identified four conditions for attributing a disease to a particular pathogen. These are known as *KOCH's postulates*—

- (i) The disease causing organism must be found in all the animals that have the disease.
- (ii) The pathogen shall be isolated and grown in pure culture on an artificial culture medium (mostly agar)
- (iii) Inoculation of pathogens from culture into the healthy person causes the characteristic symptoms in the experimental animal.
- (iv) The same organism shall be recovered from the inoculated diseased animal.

Pathogens

The list of disease causing organisms is summerised in table 55.3

Epidemiology *(Spread of Diseases)*

The causative or pathogenic agents may spread through coughing, sneezing, contact and use of improperly washed utensils, clothes or through improperly washed hands. Some diseases spread through food, milk and water which may carry a number of germs. Another group of diseases spread through lesions on the skin and cut wounds. Still another gorup is carried by some intermediary carrier called *vector*. The carriers are those animals which harbour the germs of the disease in their body but do not show any symptoms and transfer the germs from one man to another. These can be summarised as under follows—

A. Direct Transmission

1. *Contact transmssion* i.e. through contact between infected and healthy persons.
2. *Droplet transmission* i.e. through sneezing, coughing, spitting and talking.
3. *Contact with soil* which contains saprophytic disease-causing agents.
4. *By bite of an animal.*
5. *Transplacental transmission* from mother to foetus.
6. *Through blood transfusion*

B. Indirect Transmission

1. *By vectors*—Transmission of pathogens by arthropod/insect vector or any other living organism.
2. *Through contaminated food and water*
3. Through transfusion of diseased blood.
4. *Through aerosol sprays*, smoke, dust and automobile exhausts.
5. Through contaminated clothes, crockery, toys, door handles, taps and surgical instruments.
6. By unclean hands and fingers.

Pathogenicity

The disorders in the body may be caused by the pathogenic organism either by destroying blood cells or any other tissue, by using food material or by the production of some *toxins* into the body of host. The *toxins* are poisonous substances released by the pathogenic organism, which travel to other parts and cause damage. Their action may be general or affecting a specific tissue.

Natural Protective Measures or Body Defence Mechanisms

Human body has a number of mechanisms to protect against the harmful effects of the parasite.

These are—

1. Skin—The skin protects the body against the invading germs.

2. Body secretions—The slimy *mucus* secreted by the mucous membrane of nose, throat and trachea is injurious of bacteria. Tears in the eyes destroy and wash away micro-organisms or dust particles entering the eyes. The acid secreted by the stomach wall kills germs.

3. White blood corpuscles—If bacteria enter the body through injured skin or any other tissue containing blood vessels, have to fight against the white blood corpuscles in our blood and lymph. It is during this fight that we develop fever. The dead microbes and exhausted blood corpuscles are deposited at the wound as pus.

4. Antibody formation—The blood also produces some complex proteins called *antibodies* to fight against the invading organisms. A specific antibody is produced against a specific invading organism. Any organism or its substance that causes antibody production, is called an *antigen*.

5. Immunity—Different individuals vary in their capacity to produce antibodies and fight against the disease. Some of them are very **resistant** to the disese, while others are **susceptible** to it. The resistance of our body to disease is called **immunity**. The immunity can be of two types:

(i) **Natural immunity**—Certain persons do not catch the disease so easily as others, while some do not get the certain diseases at all. Such persons are called immune and this sort of natural resistance is known as **natural immunity.**

(ii) **Acquired immunity**—The immunity to certain diseases can be acquired by getting dead or weak germs injected into the body or by getting antibodies from other animals. This method of getting immunizations is known as *vaccinations* and the diluted or dead germs capable of inducing immunity form the *vaccine*. The vaccine enables the body to build up its own antibodies against the specific germs, which enables the body to fight against any fresh infection and thus makes the body immune. This is known as *acquired immunity*.

4. Control and Prevention of Communicable Diseases

Since communicable diseases are contagious and can turn into epidemic, the control on their spreading and the prevention are very essential. For early men the diseases were caused by demons and evil spirits. The cure included pleasing the evil spirits with charms and magic. The belief is still prevalent in certain backward castes in India and in other parts of the world. However, today man knows the causes and cure of so many diseases. This has been made possible by the regular and unsustained contributions from three different branches of biology. These are:

1. Parasitology—Researchers in the field of parasitology provide information about various parasitic organisms that cause disease in man and other animals and plants. Its foundations was laid only after the invention of microscope in 1835, which enabled us to study minute organisms. LOUIS PASTEUR and ROBERT KOCH (1876-1885) established *'the germ theory of disease'*. PASTEUR showed the presence of bacteria in wine, beer and milk. KOCH demonstrated rod-shaped bacteria in the blood of cattle that died of anthrax and showed that these bacteria could produce anthrax in a healthy cattle. Today, most of the bacterial diseases have been well understood. In 1890, the first virus tobacco mosaic virus was discovered by IWANOWSKY. Since then a large number of viral diseases have been discovered.

2. Epidemiology—It has helped in knowing the mode of transmission of various communicable diseases or the disease causing pathogens and has enabled us to devise proper protective measures to check the spread of check. JOHN SNOW is regarded as the father of science of epidemiology. While investigating epidemic Asiatic cholera germs was the cause of epidemic and SIR RONALD ROSS associated the spread of malaria to *Anopheles* mosquito.

3. Immunology—It deals with the development of a defence mechanism in general public for resisting attack. Immunology has provided an effective protection against the attack of bacteria and viruses. The discovery of smallpox vaccine by EDWARD JENEER was the first milestone in the field of immunology. LOUIS PASTEUR developed innoculation against anthrax and rabies.

Factors Influencing Infection

A number of factors contribute to cause the infection by germs or other disease causing organisms. These can be:

1. Tissue affinity—Different parasites or

pathogens survive and multiply in different parts or tissues of the body. For example, *Ascaris* lives in intestine and *Filaria* in lymph nodes and in blood. It means the pathogens are tissue specific and fail to survive, if they reach some other tissue. Some organisms have affinity for one type of tissue at one stage of the life cycle and for another eye of tissue at some other stage. As malarial parasites live in R.B.Cs of human blood during assexual multiplication and can complete their sexual cycle only if these reach the stomach of mosquito.

2. Hypersensitivity—Animal tissue becomes abnormally sensitive to certain bacterial cells or their metabolic products or toxins. Due to the hypersensitivity, a particular person becomes more prone to a infection.

3. Infective dosage—It is the number of organisms capable of producing the disease in the host. The infectrive dose varies with the host and the strain of pathogen. The infective dose is dependent on the virulence of the strain.

4. Portal of entry—The route through which the pathogen enters the host body to produce the disease is called *portal of entry*. For example, germs of typhoid and cholera must enter through mouth into the ailmentary canal; in diptheria, lung tuberculosis and pneumonia pathogens must get into the respiratory tract and in malaria the parasite has to enter the blood stream.

5. Communicability—Communicability or spread of disease causing pathogens is another very important factor, as the pathogens being internal parasites are unable to reach the next host, rather, the host with pathogens will due due to severity of infection and will destroy the pathogens along with. Communicability requires two factors—*(i)* a proper host which can get infected with the germs and *(ii)* a proper agent which can transmit parasite from one host to another. For example, spread of malaria is possible only due to *Anopheles* mosquito. The germs of tuberculosis are carried by air.

A. DISEASES CAUSED BY VIRUSES

Viruses are all parasitic and can multiply only inside the living system. Some of them cause deadly diseases in man. The viruses are causative agents of diseases was demonstrated by IWANOWSKI in 1892 and the first animal disease covered to be due to virus was *'foot and mouth disease'* of cattle. A few of the common human diseases caused by viruses are discussed here.

1. Chicken-Pox

Chicken pox is highly contagious disease. Generally, the children of less than 10 years of age suffer from this disease. An attack of chicken pox usually produces permanent immunity.

Pathogenicity and Symptoms—Chicken pox is caused by chicken pox virus. Its incubation period varies from 11 to 21 days; at the end of which skin eruptions appear. The skin eruptions begin as small red papules which grow out into pustules. These appear as clear, oval 'tear drop' vesicles and fiffer from pustules of small pox as these are not umblicated. The vesicles appear slowly and in stages and within 24 hours become cloudy. The number of vesicles determines the severity of the disease. The appearance of vesicles may be accompanied with low fever.

Epidemiology—The virus is transmitted either directly from person to person or by contact with clothings, bed linen, scabs or other articles soiled with discharge from infested person.

Prophylaxis or Preventive Measures

The vesicles on drying form scab which contains virus and is source of infection to new persons. Therefore, to avoid infection—

1. Patients suffering from chicken pox should be isolated and kept in separate room till all the crusts are fallen off.

2. Person looking after the patient should wash hands with antiseptic soap before and after attending the patient.

3. The scab should be collected and burnt.

4. The utensils, bed linen and clothes of patient should be kept separate and be boiled before reuse.

5. To avoid secondary infection, the patient should be given an antiseptic bath and his clothes should be changed daily.

6. The patient should avoid scratching by the use of mittens and keeping nails short.

7. No vaccine is available for active immunity. However, passive immunity can be induced by the use of *Zoster Immune Globulin* (ZIG)

2. Measles (Rubella virus)

Pathogenicity and clinical symptoms— Measles is another contagious disease of childhood caused by a virus which has RNA as the hereditary material. Its incubation period is 10-12 days. It begins with common cold and headache, followed by fever, cough and sneezes. Its common symptoms are skin erruptions, fever, inflammation of mucous membrane of nasal, buccal and pharyngeal region. This results in severe cough and may even lead to pneumonia as a secondary infection. The conjuctiva of eye may also develop lesions causing irritation. The disease subsides after three days, but it takes about 10 days for complete scaling.

Epidemiology— The disease is air-borne and spreads through the mucous secretions of nose and throat of the infectied person.

Prophylaxis or Preventine Measure— 1. The patient must be isolated in a warm and airy room.
2. He should be protected from cold and direct air.
3. The body should be cleaned twice with luke-warm water.
4. Should be allowed to take complete rest.

Treatment— 1. Isolation of the patient is the first step to avoid inflection of healthy persons.
2. Active immunization against measles is now possible.

Edmonston B-vaccine prepared from chick embryo cells are used for active immunization. Passive immunization is also achieved by inoculating *globulin*.

3. Rabies or Hydrophobia

Rabies is an acute viral disease of central nervous system. The virus is called 'street virus'. It is introduced in the blood of man by the bite of rabied dogs , cats and other wild animals.

Symptoms— The virus first stimulate and then destroy the cells of brain and spinal cord. The symptoms of the disease include severe headache, high fever, severe and painful spasm of muscles of throat and chest so that patient feels restlessness, choking, convulsions, and inability to swallow even liquid food. He feels thirsty but fear from the sight of water, hence **hydrophobia** is another name

for this disease. The patient has a very painful death.

Treatment— The treatment of rabies was developed by LOUIS PASTEUR and is known as *Pasture's treatment*. Person bitten by rabied dog is given a series of 14 injections of vaccine one each day. The vacine is prepared from the spinal cord tissue of rabbit artificially infected with rabies virus. The injection of vaccine induceds formation of antibodies in the patient.

Prophylaxis— The only way to prevent rabies is (i) Complete immunization of pats (dog, cat, etc), (ii) Isolation or Killing of rabied dogs which become mad due to the presence of this virus.

4. Polio or Poliomyelitis

Pathogenicity and clinical symptoms— This disease is caused by the smallest known virus (about 10 mu in diameter). It affects the central nervous system and destroys the large motor cells in the dorsal horn of spinal cord which control the activites of skeletal muscles of limbs. Without nerve impulse the muscles fail to work and infected limb or limbs get paralysed making the handicapped or crippled. Earlier, it was known that only infants are infected but it can occur in adults as well, but in India it is more common in children.

Epidemiology— The virus spreads primarily from the faecal matter of patient and is transmitted by flies or by contaminated food and water. The virus multiplies in the intestinal wall and then enters the blood and lymphatic system and from there reaches the nervous system.

Prophylaxis— The development of passive immunity by poliomyelitis vaccine is the only effective method to check infection.

The first *polio* vaccine was prepared by JONAS SALK (1953) at University of Pittsburgh by killing polio-virus with formaldehyde. The killed virus is known as 'Salk-Vaccine' and injected to develop immunity. However, now SABIN et. al have prepare an oral polio vaccine called **OPV**. It consists of living but tamed polio virus.

B. DISEASES CAUSED BY BACTERIA

The bacterial diseases are most **dreading** diseases. The following table gives the **summary** of a few common bacterial diseases.

Table 55.5: Bacterial Diseases and their preventive measures

Disease	Causative Agent	Transmission	Nature and symptoms	Preventive Measures	Cure
1. Tuberculosis	*Mycobacterium tuberculosis*	Through air	Bacteria invade every tissue of the body and destroy it. Lungs are more commonly infected. The fever is due to *tuberculin*—a toxin secreted by the bacteria. Cough, fever, sputum.	Avoid dark, polluted, and congested areas.	Fresh air and rest. Use of *Para-amino Salicylic acid isoniazide* and removal of infected lung in advanced stages.
2. Diphtheria	*Corynobacterium diphtheriae*	Through unwashed cups, glasses	Bacteria grow in a mucous membrane on the wall of throat and block the air passage. Toxins produce high fever and damage to heart and nervous system.	Use clean utensils and do not eat in the same plate or bowl.	
3. Typhoid	*Salmonella*	Through food	Damages the intestinal wall. Causes fever and wekness. Fever may last a few weeks. Relapse of fever is very common.	Proper sanitation, cleanliness; immunization	Use of *Chloromycetin* (in dosage recommended by physician)
4. Cholera	*Vibrio comma*	Through food	Causes violent diarrhoea, vomiting, muscular cramps	Avoid eating, uncovered contaminated and decomposed food and fruits.	
5. Leprosy	*Mycobacterium leprae*	Through prolonged contact	Chronic infection of the skin and other tissues. Forms ulcers, nodules, scaly scabes and deformities of finger and toes.		
6. Tetanus	*Clostridium tetani*	Through contact with soil, dust, rusted iron, nails and other iron objects, cow or horse-dung	Affects the neuromuscular junctions resulting in painful, contraction of major muscles of neck and jaw. Causes death.	Take an antitetanus-oxide injection every year of after every injury.	

Disease	Causative Agent	Transmission	Nature and symptoms	Preventive Measures	Cure
7. Plague	*Pasteurella Kestis*	Through rat, mice, squirrel and other rodents from rat to rat by fleas and from rat to man by bite of fleas.			
(i) Pneumonic plague affects lungs					
(ii) Bubonic plague results in swellings at different places on the body and		1. Use of DDT to kill fleas.		Use of sulpha-drugs and streptomycin.	
(iii) Septicaemal causes destruction of R.B.Cs.		2. Extermination of rats. 3. Use of vaccine.			
8. Gonorrhoea	*Nisseria gonorrhoeae*	Spreads during sexual intercourse	A veneral disease caused by the infection of mucous membrane of urinogenital tract. Causes pain in the joints and may lead to female sterility.	Avoid sexual intercourse with diseased patient.	Use sulphanomides or antibiotics
9. Botulism	*Clostridium botulinum*	Through unsterilized canned food	Releases toxins which poison the food. This causes vomits, double vision. Affects nervous system and may even cause heart failure	Use well boiled and sterilised food.	

1. Tuberculosis

Pathogenicity and symptoms—Tuberculosis is caused by a tiny rod-shape bacteria. *Mycobacterium tuberculosis* in persons who live in dark and dingy, congested part of large cities. It can infect any system of the body but mostly resides in lungs, where it forms small tubercles. The bacteria of tuberculosis release a toxin—*tuberculin* which causes fever, loss of apetite and weight. The symptoms of lung tuberculosis are fever, cough, and sputum containing blood.

Epidemiology—The T.B. patient coughs out a large number of bacilli in the sputum and nose discharge. These contaminate air. Healthy persons get infected by breathing contaminated air. Therefore tuberculosis is most common in crowded city slums because of unhygenic conditions, dark and dingy and congested conditions. Fatigue, malnutrition and presistant cold decreases body resistance against bacterial infection.

Diagnosis—The actual diagnosis of tuberculosis is made by (i) chest X-ray, (ii)sputum test and (iii) gastric analyais.

Treatment—Until recently fresh air and rest were the only remedies. Therefore, T.B patients were kept in sanitorium built on some hilly resort. However, now *streptomycin, PAS (para-amino salicylic acid), isoniazid and related drugs* are used effectively for its treatment. In advanced cases of infection, the removal of infected part of the lung is the other alternative.

Morden treatment of tuberculosis is based on six main factors: namely rest, diet, drugs, surgery, rehabilitation and health education. Vaccination with *BCG vaccine* right after birth or afterward provides considerable protection against infection with tuberculosis bacillus.

According to latest statistics by ICMR (Indian Council of Medical Research) it is estimated that about half-a-million of them die every year. About two million of Indian population is carrier of tuberculosis bacteria. Because of this wide-spread occurence of this diseas Indian Government has launched *National Tuberculosis Control Programme*. It include detection of the disease, its treatment, BCG vaccination avd educating people about its preventive measures.

2. Typhoid

Pathogenicity and symptoms—*Typhoid fever* is caused by acute infection of the intestine by rod-shaped bacteria, Salmonella typhii. The bacterium damages the intestinal wall and produces continued fever, often with delirium, slow puls, abdominal tenderness and a rose-coloured eruption or rash. The fever last for 2-3 weels, but it may relapse if other parts of the body like bone-marrow, splen or gall-bladder are infected through blood stream. Through typhoid is not fatal but it may cause death due to haenorrhage or puncturing of intestine.

Epidemiology or infection—Typhoid bacteria are present in the stool and urine of the patient. These bacteria are deposited on human eatables and water by flies. Therefore, infection occurs through contaminated food and water. Sometimes, a person carrying typhoid germs may not suffer from the disease but helps in its spreading.

Prophylaxis and Treatment—*Chloromycetin* is the effective drug against typhoid. The prevention of infection depends on proper community sanitation, personal cleanliness,water supply system and protection of food and water from dust and flies. Immunization is also advisable during epidemic conditions.

3. Leprosy

Symptoms—Leprosy is a chronic infectious disease, more dreadful than any other communicable disease because of social stigma attached to it. Though, it is considered to be a hereditary disease, it is an infectious disease caused by the bacterium *Mycobacterium leprae.*

Leprosy is characterised by lesions of skin and peripheral tissues involving peripheral nerves, so that the infected areas become benumbed. The other symptoms include discoluration of skin, lesions, ulcers, nodules, scaly skin, deformity of fingers and toes and decay of body parts.

Epidemology—The disease is transmitted only through prolonged contact with the diseased part or person.

Prophylaxis and Treatment—Being a communicable disease, the patients should be isolated. Government has established a large number of lepor-homes where lepros are properly looked after. The National Leprosy Control Programme of Indian Gvernment is organised for detecting, treating and rehabilitation of the patients.

Leprosy is more common in Africa and Asia and about 3 million Indians are suffering from this disease.

4. Cholera

Cholera is a dreadful contagious disease that usually breaks out in epidemic form during fairs, after flood or any other natural calamity. Cholera spreads in crowded places with poor sanitation. It has persisted in India for thousands of years and often breaks out in summer and rainy season.

Pathogenicity and Symptoms—Cholera is caused by a small, highly motile, comma-shaped bacterium-*Vibrio comma* or *Vibrio cholerae* which enters the digestive tract through contaminated food and water. The symptoms appear with 6 hours to 2-3 days after infection. The symptoms include acute diarrhoea, vomiting and muscular cramps. The stool has rice-water appearance (white and watery). In advanced stages, cholera results in suppression of urine, dehydration, loss of minerals and may lead to death.

Prophylaxis—The preventive measures include—
1. Proper heating of food.
2. Boiling of drinking-water.
3. Proper disposal of wastes.
4. Proper sanitary conditions.
5. To keep the eatables covered so that flies do not contaminate the food.
6. To avoid eatables from the market and from fairs; and not to purchase cut and putrifying fruits.
7. Cholera vaccination should be taken during epi-

demic or while going to cholera infested areas.

5. Diphtheria

Diphtheria is an acute contagious disease of respiratory tract more common in children up to 5 years of age but adults may also get infected. It is caused by a rod-shaped, nonmotile bacterium *Corynebacterium diphtheriue.*

Symptoms—These bacteria infest membrane of the respiratory tract and depending on the location of infection, diphtheria can be (i) *nasal diphtheria, (ii) pharyngeal diphtheria* and *(iii) laryngo—tracheal diphtheria.* The symptoms of diphtheria, therefore, depend upon the site of infection and immunization state of host.

The excessive growth of bacteria in the mucous membrane of throat or respiratory tract blocks the respiratory passage causing difficulty in breathing and ultimately death occurs due to choking. The bacteria produce toxin which causes high fever, damage to the heart and nervous system.

Treatment and Prophylaxis—The only treatment is administration of diphtheria antitoxin in the early stages of attack, i.e. within 12 to 14 hours of the appearance of the symptoms. If antitoxin is given after 24 hours, it proves to be ineffective.

To avoid infection children are given an injection of diphtheria toxin when they are very young. Now this injection is given along with tetanus and whooping cough by *triple antigen.*

6. Tetanus

Tetanus is a serious and fatal disease caused by bacterium-*Clostridium tetani.* It enters the body through deep wounds. In man it produces a water soluble toxin called *'tetanospasmin'* which is transported to the nervous system and affects neuromuscular junctions, resulting in painful contraction of muscles of neck and jaws followed by the paralysis of thoraic muscles. The patient feels difficulty in opening mouth (locked jaw disease). Ultimatly it leads to the death of the patient.

The tetanus bacterium grows in the intestine of horses and other grazers without causing any harm to them. It, therefore, occurs in abundance in the dung, soil, dust, rusted iron nails or other iron objects. Infection occurs when wound or cut are exposed and get contaminated with dust, soil, iron object or dung. It is, therefore, advisable to have *antitetanus toxoie* injection in case of an injury in a road accident. Moreover, the cut surfae be kept properly covered and bandaged, so that it can avoid contamination. Vaccination of *tetanus toxoide* produces immunity.

DISEASES CAUSED BY PROTOZOA

1. Malaria

Pathogenicity and Symptoms— Malarial fever is one of the oldest and most dreadful disease of mankind, spreading as an epidemic. Even now when science of medicine has greatly advanced about half a million people die every year in the world.

It is caused by a unicellular organism *Plasmodium.* The disease is characterised by high fever (upto 105-106°F) with shaking chill, severe headache and nausia. The fever subsides with profuse sweating. The cycle of chill, fever and sweating is repeated after two or three days depending upon the speicies of malarial parasite.

Type of Malaria	Species	Incubation	Recurrence of fever
1. Benign tertain malaria	1. *Plasmodium vivax*	10days	48 hours
2. Malignant tertain malaria.	2. *P. falciparum*	10 days	24-48 hours
3. Mild tertian malaria.	3 *P. ovale*	14 days	48 hours
4. Quartan malaria.	4 *P. malariae*	27-37 days	72 hours
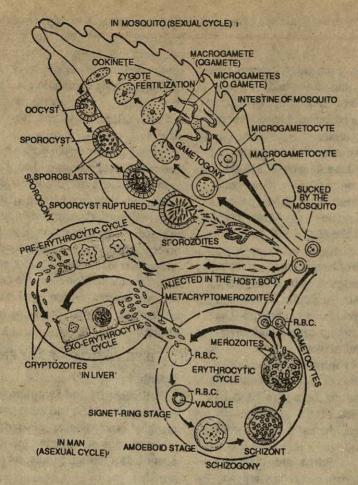
Fig. 55.1 Life history of malarial parasite.

Diagnosis—Diagnosis of the disease can be made by observing under microscope the blood smear of the patient's blood during chill and fever.

Epidemiology *(Infection)*—Female anophelene mosquito carries malarial parasite from an infected person to a healthy one and thus helps in the spread of disease. Since mosquitoes are more frequent in low lying swamps and marshes, malaria appears as a regular feature in these areas and in tropical and subtropical regions.

The infective stage is a minute, sickle-shaped sporozoite which is injected into the blood of a healthy human being by the bite of infected *Anopheles* female mosquito. It damages liver cells and the red blood corpuscles and releases a yellow pigment *Schuffiner's granules*. Deposition of this pigment in blood produces yellowish colour of eyes and skin. The destruction of RBCs, in large number causes weakness and release of toxic substance—*heamozoin* which causes chill and fever.

Though in the past, malaria was associated with bad air (*mala, +aria,* air) and swampy places. It was in 1880 that a French Army Surgeon ALPHONSE LAVERAN stationed in Algeria, discovered the cyst-like protozoan parasite in the RBCs of a malarial patient. In 1894, SIR RONALD ROSS, an Indian Army doctor established that its spread is associated with mosquito, for which he was awarded Nobel Prize in 1902.

Prophylaxis and Treatment—Prevention and control measures for malaria involve the elimination of mosquito which can be achieved by (i) killing the adult mosquito by spraying DDT, (ii) killing the larvae and pupae by spraying surface of ponds with kerosene oil or with some

insecticide, (iii) filling up ditches and ponds and draining swampy places to prevent breeding. **World Health Organization** (WHO) and **National Malaria Eradication Programme** (NMEP) have taken measures on war-footing to eradicate malaria from India and a good success was obtained. However, once again cases of malaria are on increase.

Effective drugs for treatment of malaria are *quinine, mepacrime, paludrine, chloroquine, primaquine* etc.

2. Amoebiasis (Amoebic dysentery)

Amoebic dysentery in man is caused by an amoeboid protozoan parasite, *Entamoeba histolytica*. It infests the upper part of colon. Inside the intestine, it may lie in lumen feeding on bacteria etc. and causing no apparent effect on the host except frequent diarrhoea and constipation. In other cases *Entamoeba* may invade the intestinal wall and destroy the mucosa feeding upon the red blood corpuscles, tissue debris and bacteria.Here it may erode the submucosa, cause ulcers or babcesses in the intestinal wall. When ulcers burst blood and mucus pass out along with the stool, resulting in acute amoebie dysentery. The symptoms of infection in chronic condition are abdominal pain, nausea, flatulence and bowel irregularity with fatigue and headache.

Epidemiology—The disease spreads through contaminated food and water, raw vegetables, that are deposited by the cysts of parasite. The infected persons or carriers pass the cysts of parasite in their stool. These cysts may be deposited by flies on the food or may contaiminate water and green vegetables.

Treatment and prophylaxis— The treatment includes administration of antibiotic medicines such as *Fumagillin, Terramycin, Aureomycin* in severe infections.

The preventive measures include—
1. Washing of hands before taking meals after toilet.
2. Protection of food and water from flies and cockroaches.
3. Proper sanitation of roads, streets and open drains.
4. Purification of driniking water.
5. Proper disposal of sewage.

6. Avoiding the use of raw vegetables or these should be first soaked in potassium permanganate.
7. Chemical treatment of human faeces.

D. DISEASES CAUSED BY HELMINTHES

1. Disease caused by Roundworm (*Ascaris lumbricoides*)

Ascaris (roundworm) is an intestinal parasite, living in the large intestine of man especially in the children. It obtains digested food from the host. As many as 500 to 5,000 adult round worms may be present in a single host.

The presence of parasite is not fatal. Its harmful effects on the host depend upon the severity of infection. Presence of few worms (i.e. mild infection) produces no visible effect on the host. Heavy infection with round worms casues indigestion, abdominal discomforts, acute colic pain, appendicitis, gastric ulcers accompanied with diarrhoea, vomiting and a slight temperature.The patient becomes weak and anemic. The toxins liberated by the worm may cause delirium, convulsions, coma and general nervousness.

Presence of very large number of worms may cause blockage of intestine and proe fatal. These may produce peritonitis by destroying the intestinal wall. These even migrate and injure lungs, and liver.

The adult round worm is about 20-40 cm. long. The female is longer than male. A female *Ascaris* lays as many as 27,000,000 eggs in its life time with deposition of 2,00,000 eggs daily. The eggs are shelled and come out of the host body along with the faeces. These contaimnate food, water and raw vegetables. The infection to new host takes place when eggs are swallowed accidentally a long with the contaminated food or water.The larva is released in the duodenum. It penetrates the mucous membrane of intestine and enters the portal system. Once in circulation, it enters liver, heart and finally reaches the lungs from where it comes outinto pharynx through trachea. From pharynx it reaches the alimentary canal and causes infection.

Prophylaxis or Preventive Measures—To avoid the infection from *Ascaris* the following mesures should be taken:-

1. The use of raw vegetables and contaminated water should be avoided.
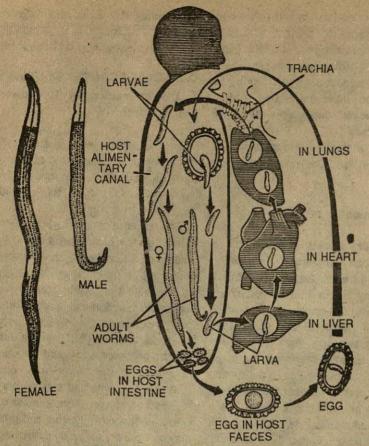
Fig. 55.2 Life cycle of round worm .

2. Sanitary toilet and effective sanitary disposal of faeces should be provided.

3. Raw stems, leaves, fruits and roots, which have been grown by the use of night soil fertilizer should be thoroughly washed and properly cooked.

4. Children should be asked to wash their hands carefully and properly before handling the food.

5. Proper hygienic measures should be adopted and sanitary education should be given to the people.

Adult worms can be removed by administring a mixture of oil of chenopodium and tetrachlorethylene or Hexyl resorcinol crystals in gelatin capsules.

Disease Caused by Filaria

Filarial worm, *Wuchereria bancrofti* lives in

Fig. 55.3 Adult female and male filarial worm; anterio part of adult wormen enlarged.
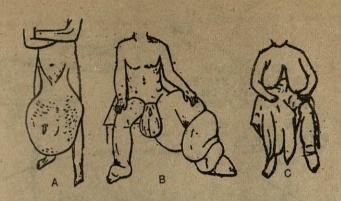
Fig. 57. A Person suffering from elephantis (filariasis)
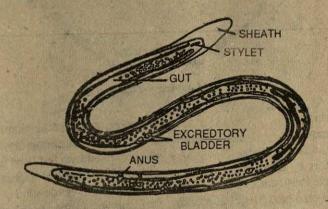
Fig. 55.5 Detailed structure of microfilaria of Wuchereria

lymphatic vessels and lymph glands and causes a disease, called filariasis or elephantiasis.

Pathogenicity and Clinical Symptoms

The pathogenic effect is produced by the adult worm living or dead. The living adult causes mechanical irritation and deposits metabolites. As a result the lymph vessels get obstructed. The dead worms also block the lymph vessels. All these initiate proliferation of endothelial cells of lymph vessels leading to inflammatory thickening of the wall of lymphatic vessels. As a result periodic attacks of fever occur and the tissues surrounding the lymph nodes and other organs of reticuloendo-thelial system such as liver, spleen, scrotum, vulva, legs and groins become enlarged producing tumour-like-solidity. This condition is known as *elephantiasis*.

Epidemiology—The disease is transmitted by *Culex* mosquito, which carries the third stage larvae, called *microfilariae*. When infected mosquito bites a man the microfilariae are deposited on the skin near the wounds. These enter the body either through the puncture or penetrate through skin. Inside the body these move into the lymphatic channels, and metamorphose into the adults.

Treatment—The drugs used in elephantiasis are divided into three categories depending upon their effect:

1. *On adult worms—Mel. W.,* an arsenical preparation and MSZ.

2. *On microfilariae*—Diethyl carbamazine (Hetrazan, Notezine, Banocide).

3. *On infective larvae* and immature adult—Para-melaminyl phenylstibonate (Msb).

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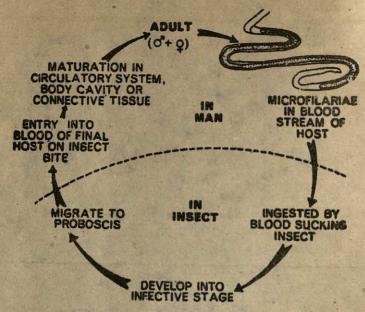
Fig. 55.6 Life history of filarial worm.

Prophylaxis—It includes:

1. Destruction of mosquitoes.
2. Protection against mosquito bites.
3. Treatment of carriers by using hetrazan.

The **National Filaria Programme** is organized by the Government to eradicate filarial infection.

3. Disease Caused by Tapeworm *(Taenia)*

The adult pork tapeworm-*Taenia solium* is an intestinal parasite of man, found attached to its mucosa by its small knob-like structure, the *scolex*. The remaining long, ribbon-like or tape-like body (*strobila*) hangs in the intestinal lumen and absorbs the digested food from the host intestine through its surface. The strobila is formed of many segments, called *proglottids*. In a fully grown *Taenia* about 800-900 proglottids are present. The proglottids are added throughout the life of the worm from a small neck or the region of proliferation immediately following the neck. Each proglottid develops a complete set of male and female reproductive organs.

Though the proglottids are hermaphrodite, usually cross fertilization between different proglottids taken place. Self fertilization occurs in rare cases. After fertilization ovaries, testes and other structures degenerate leaving only the uterus, which is filled with fertilized eggs. The proglottid with highly branched uterus is called gravid proglottid. The eggs develop inside the uterus into the embryo, called *onchosphere*. The gravid proglottids now detach from the strobila and with onchospheres are excreted out along with the host faeces. When pigs feed on human faeces, the proglottids get a chance to enter pig's intestine. In the pig's intestine the wall of proglottid and the egg-shell around the embryos are dissolved releasing a *hexacanth larva* which has six hooks. The larva bores through the intestina wall, enters the circulatory system and is finally deposited in the skeletal muscles of pig. where hexacanth larva develops into bladderworm larva also called *cysticircus*. The cysticerci appear as white cysts in the pink or red skeletalmuscles. The pig muscles with cysticerci is known as measly pork.

Epidemiology *(Infection)*—Infection of normal persons occurs by eating imperfectly cooked measly pork. In the gut of man the bladderworm comes out of the cyst and develops in to the adult by shedding of bladder and adding segments.
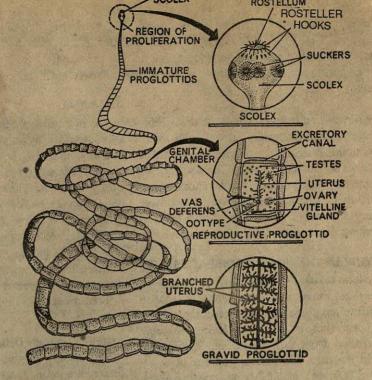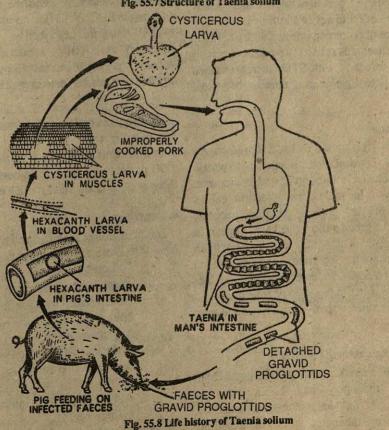
Fig. 55.7 Structure of Taenia solium

Fig. 55.8 Life history of Taenia solium

Symptoms—Presence of *Taenia* in man causes a disease called *taenisis*, which is characterised by abdominal discomfort, pain in the epigastric region, increased apetite, weakness, loss in the weight and anaemia.

Treatment and Prophylaxis—Use of *Atabrine* (Quinacrine hydrochloride) along with other antiheminthic drugs is recommended to get rid of *Taenia*. The infection with *Taenia* can be prevented by eating properly cooked pork so that the infective stage (the bladderworm) is destroyed. Sanitary disposal of human faeces also helps in preventing the spread of disease.

SEXUALLY TRANSMITTED DISEASES (STD)

The term sexually transmitted diseases or STD, covers the many infections whose causative organisms are spread by contact during sexual intercourse. These include *gonorrhoea, nonspecific urethritis* and *syphilis*. These are also called *veneral diseases* (G. **Venus**, goddess of love). Other STDs are *candidiasis* and *cystitis* which spread by contact between fingers and genital organ or by soiled towel or clothings.

The chance of becoming infected with a sexually transmitted disease is related to sexual behaviour. The risk of infection with STDs increases when a person makes love with a number of sexual partners.

1. Gonorrhoea

Pathogen— It is caused by bacterium *Nersseria gonorrhoeae*. Transmission from person to person is almost exclusively through sexual intercourse.

Symptoms— In males, its infection causes discomfort in the urethra. Urethra becomes inflamed and a green-yellow discharge appears at the end of penis. The acidity of urine produces burning sensation. Infection may spread to prostrate and bladder. In female its infection does not show any symptons but they transmit it.

Treatment and Control—Antibiotics and even penicillin.

2. Nonspecific urethritis (NSU)

It is inflammation of urethra without identifiable cause. The pathogen may be a virus or mycoplasma. The females remains unaffected but certainly transmit the infection. The male exhibits

signs and symptoms of gonorrhoea such as painful urination, urethral discharge and a frequent need for urination.

Treatment includes the use of *tetracycline*.

3. Syphilis

The disease was described in Italy in 1495. It is caused by a spiral bacterium—*Treponema pallidum*. In *males*, the infection leads to painless ulcers or *chancre* on the penis after the incubation of about 9 days. These ulcers look red and are cleared up after a few weeks. In *females*, similar symptoms develop on labia or in cervic and vagina. If untreated, secondary rash develops over the body after 6 weeks to 6 months. Tertiary signs appear in heart, liver, bones and brain. Syphilitic brain damage causes general paralysis.

Treatment. The disease can be treated with *penicillin*.

Acquired Immune Deficiency Syndrome (AIDS)

This disease hit headlines in early 1980. It was first recognised in USA in 1981. In 1984 American and French Scientists identified its pathogen—a virus nomad HCLV III (i.e. human cell leukemia virus-III) Now it is described as '*Human immuno deficiency virus* (HIV) breaks down the body immune system. It increases susceptibility to a number of diseases including skin cancer.

About 95 per cent of AIDs patients are homosexual males. Due to homosexual intercourse the epithelium lining of rectum is broken and micr-organisms manage to enter the blood stream.

At present time there is no cure for AIDS and there is 50% death rate in AID patients.

4. Hepatitis

Inflammation of liver casused by virus is called *hepatitis*. There are two types of hepatitis:

1. **Infectious virus hepartitis**—It is transmitted by infected food or drink contaminated with virus. It may occur in epidemics, especially in areas where hygiene is poor.
2. **Serum hepatitis**—It is transmitted by infected blood and blood products, such as plasma or by medical instruments contaminated with infected blood (e.g. syringe needle).

Hepatitis is also caused by poisonous chemicals,

alcohol, as a side effect of certain drugs and from a severe amoebiasis.

Complete bed rest and protein free-diet is the only recommended treatment. Recently, it is established that:-

(i) a intramuscular injection of *'Gamma globulin'* can protect against infectious hepatitis for about 6 months.

(ii) *'Australian antigen'*. Au is found in blood of patients suffering from serum hepatitis. The blood donors can be screened by testing for the antigen.

Questions

1. Define communicable diseases. Describe various means of their transmission.
2. What is a disease? Classify various diseases into specific categories.
3. Differentiate between communicable and noncommunicable diseases. Give characters, cause of infection and prophylaxis of any two communicable diseases.
4. Summarise important steps for fighting communicable diseases.
5. Describe various disease causing agents.
6. Summarize Koch's postulates about attributing a pathogen's Koch's postulates about attributing a pathogen's association with some specific disease.
7. Describe symptoms of cholera. What preventive measures would you suggest for checking its epidemic?
8. Esplain STD and AIDS. How their spreading can be checked?
9. What is DPT vaccine? Discuss its significance.
10. Name the pathogen responsible for causing AIDS. What is its effect on human body or why is it described as a dreadful disease?
11. Give in a tabular form the communical diseases and their causative agent? Which disease can be eradicated by hygenic disposal of waste?
12. Enumerate the signs, and symptoms of any two of the following diseases
    (i) Tuberculosis   *(ii)* Diphtheria
    (iii) Malaria   *(iv)* Leprosy
    (v) Poliomyelitis   *(vi)* Elephantiasis
13. What community health measures have been taken to prevent and control the spread of these diseases.
14. Differentiate between communicable and non communicable diseases.
15. Name any two diseases in man caused by viruses. Give their symptoms and epidemology.
16. What is a vector? Give its role in the spread of communicable diseases.
17. Summarize the factors that influence infection.
18. Summarize how does human body depends itself against an infectious disease?
19. What are the following—
    antigens, antibody, vaccine and serum
20. Differentiate between active and passive immunity.
21. Describe in brief the discovery of Edward Jenner.
22. Give a brief account of the contributions of Louis Pasteur and Robert Koch in establishing the germ theory of disease.
23. Write short notes on the following—
    (i) Tapeworm   *(ii)* Entamoeba   *(iii)* Poliomyelitis
    (iv) Cowpox.
24. If a person had been attacked with cowpox, what will happen if he is injected with small pox virus.
25. In a sterilized container pneumonia bacteria were heated to a high temperature and were killed. The dead bactria were injected into the body of 100 persons. All of them remained healthy. What will happen if this batch of persons is now injected with lzving pneumonia bacteria?
26. Write a bried accont of immunity.
27. What are antibiotics? How was it first discovered? Give examples of two common antibiotics.
28. Classify the following diseases into communicable, degenerative, deficiency and heritable.
    (i) Malaria   *(ii)* Atherosclerosis   *(iii)* Diabetes   *(iv)* Leukemia
    (v) Kwachiorkar   *(vi)* Athritis   *(vii)* Cyanosis   *(viii)* Cholera.
29. Name two insects that spread diseases.
30. Name two air-borne diseases caused by bacteria.
31. Why malaria is more common in marshy areas than in dry places?

32. Name two viral diseases which are spread by air.
33. Name the bacteria which cause the following diseases.
    (i) The bacterium that infects intestines and causes fever ....
    (ii) the bacteria that damages skin and peripheral tissue .... (   )
    (iii) the bacterium that causes excessive growth of mucous membrane of respiratory tract with high fever .... (   )
34. Name the toxin produced by—
    (i) bacteria that causes tetanus ....
    (ii) bacteria that causes tuberculosis ....
35. What is hydrophobia disease and how it is caused?
36. Name the scientists who demonstrated relationship of virus with disease.
37. Briefly describe the contribution of Ronald Ross to humanity.
38. What is the difference between antigen and antibody.
39. What is the difference between a male and female Ascaris?
40. Name the disease caused by the presence of *Filaria bancrofti.*
41. Give the portal of entry of the following animals—
    (i) *Wucchereria bancrofti*   (ii) *Salmonella*
    (iii) Vector   (iv) *Mycabecterium leprae*
42. Define the following terms
    (i) Vaccine   (ii) Immunity   (iii) Epidemology
    (iv) Vector   (v) Pathogen
43. What are the outstanding contributions of the following—
    (i) Louis Pasteur   (ii) Robert Koch   (iii) Lister
    (iv) Edward Jenner
44. Name a virus which has RNA as the generic material and causes disease in man.
45. Name the pathogen that causes chloera.
46. Mention stages in the life cycle of *Taenia solium.*
47. Give example of one human disease each caused by bacteria, viruses, protozoa and helminths.

□ □

Degenerative Diseases

Due to generative diseases, the vital part or parts of body become degenerative and show malfunctioning either because of some infection, insufficient blood supply or due to old age. These include diseases of heart, vascular system, nervous system and joints.

1. CARDIO VASCULAR DISEASES

1. **Heart enlargement**—the inflammation of heart muscle layers, caused by bacterial infection.

(i) *Endocarditis*—inflammation of endocardium.

(ii) *Mycarditis*—inflammation of myocardium.

(iii) *Pericarditis*—inflammation of pericardium.

2. **Rheumatic heart**—inflammation of cardiac valves due to viral infection.

3. **Congenital heart diseases**—Defects in heart at birth.

(i) **Cyanosis**—due to aperture in interauricular septum.

(ii) **Enlarged heart**—due to a connection between pulmonary artery and aorta.

4. **Coronary heart diseases**—due to reduced blood supply to cardiac muscles. These lead to *heart* attack and in severe cases to *cardiac arrest*.

(i) **Coronary thrombosis**—by blockage of coronary artery due to blood clot.

(ii) **Coronary sclerosis or artherosclerosis**—by narrowing the lumen of coronary artery by accumulation of adipose and fibrous tissue inside.

(iii) **Arterosclerosis**—by hardening of wall or loss of flexibility of artery.

5. **Hypertension**—caused due to arteriosclerosis or other heart and circulatory ailments.

1. **Rheumatic heart**—Rheumatic heart is caused as a side effect of bacterial infection. Bacteria (*Straptococci*) that cause pneumonia or infection of throat or respiratory tract release toxins which are carried to different parts of the body through blood. These toxins cause pain and inflammation of joints accompanied by fever

(rheumatism), and in heart lead to the inflammation of valves between auricles and ventricles or of the layers of heart. This causes either the narrowing the openings of the valves or incomplete closing of the valves, leading to low blood pressure. Adequate rest is the only measure for this.

2. **Congenital heart diseases**—Congenital diseases include impaired circulation and heart trouble due to defects in heart at birth. These defects include:

(i) **A permanent connection between pulmonary artery and aorta** (ductus arteriosus) which causes return of some of the blood pumped from the heart back to lungs. Therefore, heart has to work harder to supply the oxygen needs of the body. Due to overwork either the heart gets damaged or enlarged.

(ii) **Presence of an aperture** in the interauricular septum or interventricular septum. As a result some of the deoxygenated blood gets mixed with oxygenated blood and is circulated through the body. This condition is known as *cyanosis* (blue baby). Such a child has blue lips and finger tips.

The surgical repair helps in correcting these defects of heart.

3. **Coronary diseases**—The heart is a tough organ. It pumps blood to the rest of the body. For the hard work it performs, it needs a continuous supply of oxygen-rich blood. A pair of *coronary arteries* supply this blood and form a network of blood capillaries. If there is any disorder of circulation to the heart due to narrowed or blocked coronary artery, or if the amount of oxygen in the blood is low, the muscles of left ventricles do not get enough oxygen. This results in pain in the heart and chest similar to pain in leg muscles after a long

run. This painful condition is known as *angina pectoris*. The pain is sharp and usually in the centre of chest and is accompanied by feeling of suffocation, dizziness and palpitations. Angina is not a disease but a symptom of coronary diseases and a warning to seek medical treatment. In common language this condition is known as heart attack. *Heart attack* may be caused due to following coronary diseases (abnormalities in coronary arteries).

(a) **Coronary sclerosis**—This is narrowing of coronary artery or any of its branches due to accumulation of fatty substances and fibrous tissue forming a sort of nodule projecting into its lumen. This obstructs blood circulation to the heart muscles, and causes heart attack. It is a type of *antherosclerosis* only. It is the most common cause of the heart attack and heart failure.

(b) **Coronary thrombosis**–In this a blood clot or *thrombus* is formed in some part of coronary artery, which either reduces or completely cuts of blood supply to a part of heart muscles. The formation of blood clots is more frequent on those roughened surface which are formed by the break down of chalky plates from streaks of fatty deposits in the arterial wall. In complete blocade of a branch of coronary artery, the part of cardiac muscles getting supply from blocked artery fail. This is known as *myocardial infarction*.

4. **Arteriosclersis**—This is hardening of the arteries. In the old age, the arteries become narrow and less flexible. The loss of elasticity is due to the thickening of fibrous tissue or deposition of cholesterol and minerals (calcium) in the wall of blood vessels. This narrows the lumen of arteries and consequently reduces blood supply to different parts of the body. Therefore, to pump the same amount of blood to the body parts, heart has to work with more force. This increases blood pressure. The excessive high blood pressure may lead to rupturing of arteries of the brain or body causing *cerebral haemorrhage* or *visceral haemorrhage*.

In certain cases these deposits inside the artery may thicken to the extent to obstruct the blood flow seriously. This type of arterosclerosis is known as *atherosclerosis*. If artherosclerosis is caused in coronary artery it leads to *heart attack*, and if it affects the artery carrying blood to brain, it causes a *stroke*.

5. **Hypertension**—This is a high blood pressure, high enough to warrant medical treatment. It may be caused by arterosclerosis, kidney ailments, tumours of adneral gland, diseases of the brain and other defects in circulation. It is also caused by *emotional stress* (fear, worry, anxiety and excessive joy) or by *nervous tension*. Hypertension throws a strain on the heart and may damage small blood vessels in the kidneys and eyes. Strokes and coronary thrombosis are more frequent in persons with high blood pressure.

Preventive measures—The following do not dont's are suggested for keeping the heart healthy and blood pressure normal.

1. Do not smoke because smoking constructs the vessels.
2. Do not become overweight.
3. Avoid starchy, sugary and fatty food.
4. Avoid eating too much food rich in animal fats.
5. Take a sensible amount of exercise.

II. ACHING JOINTS

Aching joints is associated with old age, but it may occur at any age. This condition may result from a variety of causes.

1. Dislocation

Unintestinal physical abuse may pull the joints apart, may injure tensons, ligaments and muscles or damage the cartilage and destroy the bursae. All these problems lead to pain and inflammation of joint.

2. Arthritis

It is the disease in which joints become inflamed and swollen or may become permanently damaged, causing pain and difficulty in movement. Arthritis of two types:

1. **Rheumatoid arthritis**—It symptoms are inflammation of synovial membrane. A hard tissue is formed over the cartilage, stiffening the joint. This leads to painful movement. Finally replacement of cartilage by the new tissue causes fusion of the associated bones and the joints

become immovable.

2. Osteoarthritis—This disease is common in elderly persons. It is caused due to erosion of joint cartilage and roughening of their articular surfaces, causing pain and difficulty in movement.

3. Gout—It is caused due to accumulation of citric acid crystals in the synovial joints, because uric acid is not removed from the blood by kidney. Gout is related with diet.

There is no cure for aching joints, however drugs are available which relieve pain. Regular exercises and physiotherapy also help to some extent.

III. CANCER

Nature—Cancer is the common name for a number of diseases in which the process of cell division, by which tissues normally grow and renew themselves gets out of control. The cancer cells multiply in an uncoordinated way, independent of normal growth regulatory mechanisms and form a tumour of undifferentiated malignant cells or malignant neoplasms. These increase rapidly crowding and disrupting normal cells ultimately killing them.

These tumours are of two types:

1. Benign tumours—These tumours are enclosed in connective tissue and kept localised.

2. Malignant tumours—Cancerous cells from such tumours are carried by blood and lymph to other parts of the body, where they form secondary malignant growths. The spread of cancer cells to distant parts is called *metastasis*.

The secondary malignant growths are called *metaplastic cancers* or *secondary cancers*.

Types of Cancers

1. Sarcomas—Malignant growths arising in tissues derived from embryonic mesoderm *i.e.* cancer of bone, muscle, lymph node and connective tissue.

2. Carcinomas—Malignant growth of epithelial tissues or skin *i.e.* cancer of skin, lung, breast, stomach and pancreas.

3. Leukamias—Cancer of blood in which the number of leucocytes (WBCs) increases due to unchecked proliferation of cells in the bone narrow.

In addition, highly malignant tumours of eye, kidney and cerebellum sometimes develop in infants and children.

Causes of Cancer

Cancer is neither contagious nor heritable. It is believed that all cells carry certain cancer-producing gene—the *oncogenes*. Under certain conditions these genes are triggered inducing rapid multiplication of cells and formation of malignant neoplasms.

The agents that tend to induce cancer are call *carcinogens*. Most of them are pollutants. A few carcinogens and the cancer they produce are listed in the Table 56.1.

Table 56.1 : Carcinogens and their target tissue

S.No.	Target tissue	Carcinogens
1.	Excessive sunlight	Skin
2.	Coal-tar (3-4 benzopyrene)	skin and lung
3.	Soot	Skin and lung
4.	Cigarette smoke (n-nitroso-dimethylene)	Lungs and lips
5.	Mustard gas	Lungs
6.	Nickel and chromium compounds	Lungs
7.	Asbestos	Lungs and pleural membrane
8.	Venyl chloride (VCM)	Liver
9.	Aflatoxim (a mould metabolite)	Liver
10.	2-naphthylamine and 4-aminobiphenyl	Urinary bladder
11.	Cadmium oxide	Prostate gland
12.	Diethylstilbestrol (DES)	Vagina

In addition, exposure to X-rays, U V-rays and other forms of radiation are also carcinogenic. Continuous and persistent irritation of skin may cause skin cancer. Chewing beetle and nut and tobacco may cause cancer of mouth and tongue. Sex-hormone-*Oestrogen* also may cause cancer.

In India *Uterine – Cervical Cancer*, and cancer of mammary glands in women and *'mouth and throat cancer'* in men are more common.

Diagnosis—A number of symptoms indicate the formation of cancer in the body, such as

1. Presence of a persistent lump or thickening which can be felt by touch as in the tip, tongue or breast. Breast cancer is very common in women.
2. Any wound that does not heal quickly.
3. Any irregular bleeding or blood-coloured discharge.
4. Regular hoarseness in voice, persistent cough or difficulty in swallowing indicates throat cancer.
5. Sudden or rapid change in the form, appearance or rate of growth of a mole or wart.
6. A persistent change in bowel movement.
7. Continuous indigestion or loss of apetite.
8. Unexplained loss of weight.

Treatment

Treatment of cancer is still big question before scientists. Since cancer is not a single disease, it is unlikely to find a single cure for all sorts of cancers. Surgical removal of tumours or exposing the cancerous area to definite doses of X-rays (*radiotherapy*). Some drugs are used to fight cancer (*chemotherapy*). These drugs either stop cancer cells from dividing or are more toxic to cancer cells than to normal cells.

The common weed—*Sadabahar (Catharanthus) roseus* or *Vinca rosea*) is a source of two anticancer drugs—*Vincristin* and *Vinblastrin* used in the treatment of leukaemia.

QUESTIONS

1. Describe the causes and symptoms of the following diseases:
   (i) Mycocardinal infraction
   (ii) Skin allergy.
2. What is the difference between communicable and non-communicable diseases? Give the symptoms of tetanus. How can it be prevented?
3. Discuss symptoms of diabetes in brief.
4. Give causes and symptoms of the following diseases:

   (i) Arteriosclerosis   (ii) Angena pectoris
   (iii) Rheumatic heart   (iv) Diabetes

5. Differentiate between communicable and non-communicable diseases.
6. What is the difference between diabetes melletus and diabetes insipidis?
7. What do you understand by terms—glycosuria and hyperglycemia? With that disease these terms are associated?
8. Why emotional stress may cause heart attack?
9. Why persons after 40 years of age are recommended not to use fatty and starchy food?
10. Why danger of heart attack are more in persons who are fat?
11. What do you understand by mycardial infraction?

□ □

Inherited Diseases

Genetic diseases in human beings may be because of the following reasons:

1. Due to abnormal number of chromosome

(i) *Down syndrome*—Mongolian idiocy because of trisomy of 21st chromosome.

(ii) *Klinefelter's syndrome*—due to presence of an extra X-chromosome in male (*i.e.* male has 44 + XXY chromosomes)

(iii) *Turner's syndrome*—due to absence of one X-chromosome in female (*i.e.* an abnormal woman has 44 + XO chromosomes).

2. Due to Defective genotype

A. *Due to dysfunctioning of somatic gene*
  (i) Alkeptonuria
  (ii) Phenylketouria
  (iii) Albinism
  (iv) Infantile amaurotic idiocy

B. *Due to dysfunctioning of sex-linked gene*
  (i) Haemophilia
  (ii) Diabetes

3. Due to incompatibility of genes
  (i) ABO incompatibility
  (ii) Rh-factor incompatibility

Fig. 57-1. **Chromosomal composition of a person suffering from Down's syndrome (produced by trisomy of 21st chromosome).**

1. Genetic Disorders Due to Abnormal Number of Chromosomes

These include addition or loss of a single chromosome out of 23 pairs of autosomes. The addition of a chromosome is known as *trisomy* and loss of a chromosome out of a pair is called *monosomy*. A change in the number of a particular chromosome produces specific phenotypic characters and is called a *syndrome*.

(A) Syndromes Produced by Autosomal Trisomy

1. Down's Syndrome—This syndrome is associated with the *trisomy of 21st chromosome.* It was first described by *Langdon-Down* (1866) and was popularly known as *Mongolian idiocy* because the facial features of persons suffering from Down syndrome resemble Mongolians. The affected children have a broad forehead, short and broad neck, short and stubby fingers, a simian line in the palm and a wide gap between first and second fingers in feet. The face has moon-like aspect with widely separated eyes, flattened nose, permanently open mouth, projecting lower lip and a long protruding tongue. The victim suffers from severe mental retardation because of malformation of central nervous system.

Down's syndrome is congenital syndrome originating from the nondisjunction of chromosomes of pair 21 during meiosis. The mongoloids, therefore, have 47 chromosomes instead of 46 with three copies of chromosome no. 21. The extra 21 chromosome comes from abnormal egg in which chromosomes of 21 pair had failed to separate at the time of meiosis. Such abnormal eggs, therefore, contain 23+1 chromosomes.

Several other syndromes caused by abnormal number of autosomes are also known, such as—

(i) *Edward's syndrome* is caused by an extra 18th chromosome and is characterised by defective nervous system, malformed ears and receding chin.

(ii) *Patau's syndrome* is caused by an extra 13th chromosome and is characterised by hare-lip and cleft palate.

(B) Syndromes Produced by change in the Number of Sex Chromosomes

1. Klinefelter's Syndrome (2n=47 or 44 + XXY) — This is caused by the presence of an extra X - chromosome in males. Such males possess 47 chromosomes (44 autosomes + XXY sex choromosomes). Morphologically, these are sterile males with under-developed genitalia, sparse body hair and some degree of breast development. These exhibit mental retardation and limited intelligence. Klinefelter's syndrome is seen in one out of every 500 male births. It arises by the nondisjunction of XX-chromosomes.

2. Turner's syndrome (2n=45 or 44+X)—It is caused by the absence of one X-chromosome in female. Such females possess 45 chromosomes (one less than the normal 46). These are sterile females with poorly developed ovaries and under-developed breasts. They have webbed neck and broad chest. One in every 25,000 births suffers from Turner's syndrome.

3. Males with **XXY** (diplo X), **XXXY** (triplo-X), **XXXXY** (tetra-X) and **XXXXXY** chromosomes were observed. All these extra X arise as a result of nondisjunction of sex-chromosomes.

4. The occurrence of **XYY** chromosome abnormality was first observed in 1962 by T.H. HAUSCHKA. The extra Y-chromosome is strongly male determining and leads to overproduction of male hormone, which causes unusual height, mental retardation, over aggressiveness and criminal bent of mind. XYY genotype is present one in every 300 males.

5. Females with extra X-chromosomes (**XXX, XXXX** or **XXXXX**) show abnormal development of gonads and mental retardation. The symptoms are more severe with increasing number of X-chromosomes.

(C) Abnormalities Due to Change in the Structure of Chromosomes

Changes in the structure of chromosomes produced either by loss or addition of genes or by change in the arrangement of genes in the chromosomes are associated with abortions and with various congenital diseases. Down's syndrome similar to 21-trisomy is produced by exchange of parts between nonhomologous chromosomes 21st and 14th chromosomes or between 21st and 15th chromosomes (*translocation*). Deletion of genes by loss of a part of 21st chromosome produces *leukemia*. Similarly, loss of a part of 5th chromosome produces *cat cry syndrome*.

(D) Abnormalities Due to Gene Mutations

Changes in the structure of genes (gene mutations) lead either to the loss of functioning or to their abnormal functioning which produce many diseases in human beings. These mutations may occur in the genes located on autosomes or on sex-chromosomes. The *autosomal mutant genes* are inherited in Mendelian fashion. *Sickle cell anaemia, phenylketonuria, alkaptonuria, schizophrenia, clefted palate* and *hair-lip* etc. are heritable autosomal characters which are produced by mutant genes. The mutant genes may be dominant or recessive.

1. Disorders Due to Dysfunctioning of Somatic :
(Due to recessive somatic mutations)

(i) **Sickle cell anaemia**—It is a disease of human beings, found specially in Negroes. The R.B.Cs. in this disease become *sickle-shaped* in venous blood owing to the lower concentration of oxygen. This causes rupture of cells and severe haemolytic anaemia. The molecular basis for the disease lies in the difference of one amino acid in two of the four chains of protein *globulin* of haemoglobin.

Hemogolobin is a compound of *heme* and *globulin*. It is formed of about 600 amino acids. These amino acids are arranged in four polypeptide chains, two identical α-*chains* and two identical β-*chains*. The sickle-shaped hemoglobin (HbS) differs from normal hemoglobin (Hb^A) in the presence of *valine* in place of *glutamic acid* in peptide number-seven of the β-chain (see Fig. 57.2).

(ii) **Alcaptonuria**—The urine of persons suffering from hereditary disease alcaptonuria turns black on exposure to air due to the presence of a substance *alcapton* (homogentisic acid) in their urine. In

β-change of hemoglobin-A		β-chain of hemoglobin-S	
(1)	Valine	Valine	(1)
(2)	Histidine	Histidine	(2)
(3)	Leucin	Leucin	(3)
(4)	Leucin	Leucin	(4)
(5)	Threonine	Threonine	(5)
(6)	Proline	Proline	(6)
(7)	Glutamic acid	Valine	(7)
(8)	Glutamic acid	Glutamic acid	(8)
(9)	Lysine	Lysine	(9)
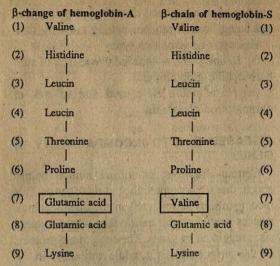
Fig. 57.2 *β-chain of normal hemoglobin and sickle-shaped hemoglobin showing difference in the arrangement of amino acids.*

normal persons metabolism of amino acid *phenylalanine* requires six different enzymes which catalyse six different steps of this pathway as shown in Fig. 57.3. The end products enter krebs cycle to release CO_2 and water. In alkaptonurics the enzyme *homogentisic acid-oxidase* required in the *conversion of homogentisic acid* into *maleylacetoacetic acid* is absent. Thus homogentisic acid is passed out in the urine, and latter turns black on exposure to air.

Phenylalanine	(1)
⇓	
Tyrosine	(2)
⇓	
p-hydroxyphenyl pyruvate	(3)
⇓	
Homogentisic acid	(4)
⇓	
Maleylacetoacetic acid	(5)
⇓	
Fumarylacetoacetic acid	(6)
⇓	
Fumaric acid and Acetoacetic acid	(7)

Fig. 57.3 *Pathway of phenylalanine metabolism in man showing the basic cause of disease of alcaptonuria.*

The above observations indicate that in normal persons, the gene which controls the production of enzyme homogentistic acid-oxidase fails to synthesize the necessary enzyme in alcapnurics.

(iii) **Phenylketonuria (PKU)**—This disease is caused by the absence of the enzyme which catalyses the first step in the metabolism of *phenylalanine*. As a result, phenylalanine accumulates in the blood. This causes mental retardation, pale skin and a tendency to epileptic seizure.

2. Sex-linked Disorders

The sex-linked traits exhibit a particular mode of inheritance and are more common in males. The genes for sex-linked characters are located on sex-chromosomes, mostly on X-chromosome, Y-chromosome lacks their alleles. Since, a woman has **XX** and a man has **XY** sex-chromosomes, a sex-linked gene is present in duplicate in woman but singly in man. Most sex-linked characters are recessive. Therefore, in males a sex-linked recessive character appears only when its gene is present singly, while in female it appears only when the recessive gene is present in both the X-chromosomes. The female which have a normal gene is one X-chromosome and a recessive gene in the other one do not develop the recessive character but transmit the recessive gene to some of its off springs. Such females are called *carriers*.

Always sons receive their X-chromosome from mother and Y-chromosome from father, whereas daughters receive one chromosome from each parent. Therefore, sex-linked characters are transmitted from father to daughters and from mothers to sons. Such inheritance is called *criss cross inheritance*. Although, nearly 20 sex-linked genes are known in man, the most common examples are—

1. Red green colourblindness
2. Haemophilia
3. Diabetes

Diabetes

Diabetes is a common disease. The two totally unrelated diabetic diseases are: 1. *Diabetes mellitus* and 2. *Diabetes insipidus.*

1. Diabetes mellitus is characterised by the presence of extra quantity of sugar in the blood and its excretion in the urine. Its symptoms are—

1. Pressure of sugar in urine (*Glycosuria*).
2. High level of blood sugar (*Hyperglycemia*),
3. Excessive urination,
4. Excessive appetite and thirst,
5. Loss of weight, and
6. General weakness.

In *diabetes mellitus* body is unable to metabol-

ize blood sugar, due to insufficient insulin, a hormone secreted by Islets of Langerhans of pancreas. Therefore, glucose accumulates in the blood and is eventually passed in the urine. Long term complications may arise if diabetes introduces abnormalities in the structure of blood vessels. These may include eyes, kidneys, heart and legs. This disease may be genic *i.e., heritable*. The treatment includes—

(i) Injection of *insulin*.

(ii) Administration of drugs called *sulphonylureas* and biguanides which stimulates insulin production by pancreas.

(iii) *Diet control*—Diabetics are not supposed to take starchy and sugary food (sweats, sugar, potato, rice, wheat etc.).

Discovery of insulin hormone was done by FREDERICK BANTING and CHARLES BEST in 1921. Now it is possible to synthesize human insulin in bacteria by introducing human insulin gene is bacterial genome due latest advances in genetic engineering.

2. *Diabetes insipidus* is a rare disease characterised by excessive urination (upto 30-40 litres daily) but the urine is without sugar. It is caused due to disturbances in the secretion of hormone by the posterior lobe of pituitary gland (*Vasopressin*).

3. *Haemophilia* (Bleeder's disease)—This disease in man is restricted entirely to male members. In haemophilic men the blood fails to clot. Even a small skin injury results in continuous bleeding and may lead to death from loss of blood. In normal man it takes 2-8 minutes for blood to clot.

Haemophilia is caused by sex-linked recessive gene located in the X-chromosome, which fails to produce a factor necessary for quick clotting. Its inheritance shows—

(i) *Haemophilic man* (if survived) and married to a normal woman produces daughters all carriers (normal but carrying a gene for hemophilia on one of its X-chromosomes). Such a carrier daughter when married to normal man transmits the haemophilic gene to half of her sons (i.e. 50% grandsons of a hemophilic male are haemophilic). A haemiphilic woman is produced only if a carrier woman is married to a haemophilic man.

Haemophilic females are very rare because a girl with severe bleeding would die by the time she reaches adolescence and chances of homozygous girl being born in random mating are very rare.

Haemophilia is of two types—

(i) *Haemophilia A*—caused due to lack of anti-haemophilic globulin; and

(ii) *Haemophilia B*—caused due to lack of plasma thromoboplastin.

DISEASES DUE TO INCOMPATIBILITY OF GENES

Certain disorders in normal human beings appear due to incompatibility of their genes. This incompatibility is reflected in the chemical substances (*antigens* and *antibodies*) whose synthesis is regulated by genes. The antigen are proteins on the surface of RBCs, while antibodies in the plasma. Incompitability between antigens and antibodies may lead haemolytic disorders and may prove fatal. Two well studied incompitability are

1. ABO blood group incompitability
2. Rh blood group incompitability

ABO Blood Group Incompitability

In human RBCs the two antigens are found—antigen-A and antigen-B. Depending upon the presence or absence of antigen, the blood group in human beings may be classified into following four groups.

1. *Blood group A*—has antigen *A*
2. *Blood group B*—has antigen *B*
3. *Blood group AB*—has antigens *A* and *B*
4. *Blood group O*—has neither A nor B antigen.

These ABO blood groups were discovered by CARL LANDSTEINER (1900). If a person has an antigen on its RBCs, his plasma contains natural antibodies against the other antigen. For example, a person having *antigen A* has antibodies (**anti-B**) in plasma that coagulates or clumps RBCs of blood group B. Similarly, blood plasma of blood group B contains antibodies **anti a** for A corpuscles; O blood group contains both the antibodies **anti a** and **anti b**, whereas blood group AB has none. These antibodies are usually designated by Greek letters α and β. The following table represents the antigens and antibodies present in persons of different blood groups:

Blood Transfusion

The individuals of different blood groups are perfectly normal but the incompatability is

Table 57.1 : Blood Groups, their Antigens and Antibodies in Man.

Blood Group	Antigens on R.B.C.s	Antibodies in Plasma
1. A	A	anti b or β
2. B	B	anti a or α
3. AB	A and B	None
4. O	None	both anti a and anti b or α and β

agglutination may cause serious consequences and may prove fatal. That is why doctors make careful tests to determine what blood must safely be used in transfusion. It can be blood from the same blood group. However, the R.B.C.s of blood group O individuals lack antigens and are not clumped by antibodies present in the serum of recepient's blood. It means blood group O can be given to persons of blood group O, A, B and AB. Hence, 'O' persons are called 'universal donars'. But because of the presence of both antibodies (α and β) these persons cannot receive blood from any other group except O. Contrary to this 'AB' persons lack antibodies in their plasma, so can receive blood from A, B or AB blood groups. Such persons are called 'universal recepients'. The details of incompatibility of different blood groups is shown in the table below:

expressed during blood transfusion. The antibodies of recepients blood react against the antigens of donar's blood and cause the clumping of R.B.Cs. Thus antibodies (anti-b) present in the serum of blood group A individuals cause clumping of R.B.C.s of blood group B and vice versa. This phenomenon is known as *agglutination*. The

Table 57.2 : Showing compatibility and Incompatibility of different Blood Groups

Blood Group	Agglutinates blood of	Cogulated by blood of	May donate blood to	May Receive blood from
A	B and AB	O and B	A and AB	O, A
B	A and AB	O and A	B and AB	O, B
AB	None	O, A, B	AB	O, A, B and AB (universal recipient)
O	A, B, AB	None	O, A, B, and AB (Universal donar)	O

The incompatibility of blood groups also causes serious effects during preganancy. For example, the foetus of blood group A in the womb of mother having blood group B is attacked by the antibodies of mother. This leads to serious abnormalities like anaemia jaundice etc.

Incompatibility of Rh Blood Groups

LANDSTEINER and WIENER in 1940 discovered another antigens in human R.B.C.s and was named *rhesus antigens* or Rh-antigens because the same antigens are present in the red blood cells rhesus monkey (*Macaca rhesus*). About 85% of American population possesses this antigen and is Rh positive (Rh+).

One basic difference between ABO and Rh systems is that Rh-antibodies are not natural *i.e.* they are not present at birth but are synthesized in Rh- persons in response to the presence of Rh-antigen.

Both Rh+ and Rh- persons are quite normal. Incompatibility stems when Rh- blood comes in contact with Rh+ blood either due to transfusion or during pregnancy.

1. When Rh+ blood is given to Rh- person, the Rh-antigens induce formation of anti-Rh antibodies in the recepients blood. If such a person is again given Rh+ blood, its anti-Rh antibodies react with the donar's Rh-antigens and agglutinate the blood. The transfusion of Rh- blood to Rh+ produces no complications because no antibodies are founed in Rh+ persons.

2. Incompatibility is seen between Rh- woman and her Rh+ foteus. Rh- woman when married to Rh+ man bears Rh+ feolus. Although, the foetal and maternal blood do not come in direct contact because of the placental barrier, some foetal R.B.C.s manage to enter the maternal blood stream. The Rh-antigen on their surface induces formation of anti-Rh antibodies. These antibodies then cross the placer.ta and enter the foetus blood circulation and cause a blood disorder, *erythroblastosis foetalis*. This is an anaemia produced by the hoemolysis of R.B.Cs. in foetus. Depending on severity, the disorder may even lead to the death of baby either before birth or within few days after birth.

Usually, the first child of such parents is nearly normal because at least one pregnancy is required to sensitize the mother. The reaction of Rh- woman against her Rh+ offspring becomes pro-
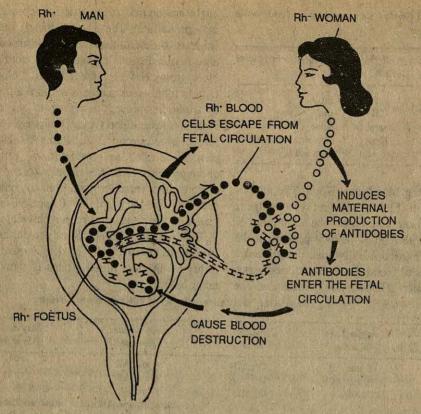
Fig. 57.2 Diagram to show the mechanism of gene incompatibility in Rh blood groups.

gressively more severe with each subsequent pregnancy.

The disorder arises only if mother is Rh negative and foetus is positive. There is no harm if the mother is Rh⁺ and foetus is Rh⁻ because the antibodies produced in Rh⁻ foetus against mother and their entrance into the maternal blood is far less in proportion to mother's blood.

GENETIC COUNSELLING

A number of lethal or disabling diseases caused by the defective genotypes and karyotypes have been recorded in human population. With an enormous increase in human population, the number of individuals with genetic disorders is also adding up gradually to the genetic load of future generations. Therefore, man is deeply concerned about his future. He is making all round efforts for improving inborn qualities of human race and to have better and healthy progeny. The efforts can be studied under the following heads:

1. Euthenic measures—These measures included improving the living conditions of human race by providing better nutrition, better unpolluted ecological conditions, improved educational and medical facilities. Therefore, euthuenic measures involve the improvement of qualities of those individuals who have already been born.

2. Eugenic measures included bringing into the world only the good germplasm *i.e.* improving the genic qualities of individuals. The term *eugenics* was coined by Francis GALTON (1885) to mean the *'science of being well born'*. The practice of eugenics has mostly taken the form of *genetic counselling*. The role of genetic counsellor can be summarised as under:

(1) Genetic counsellor educate the common man of the dangers of hereditary diseases and various genetic malformations. This can help in taking measures to prevent future recurrence of genetic defects by preventing birth of children by concerned parents.

(2) Genetic counsellors help in educating general public about the use and misuse of various informations that are revealed through scientific explorations of geneticists.

(3) Genetic counsellors can predict the characteristics of future generations and can help in plan-

ning the parenthood. As for example by testing Rh blood group of mother and father, it is possible to predict Rh blood group of child. He can warn the Rh⁻ negative woman either to marry a Rh⁻ man or not to have children, as this leads to erythroblastosis foetalis, though injections of antisera to avoid this disease have now been developed.

(4) Geneticists can tell the probability of producing infecting offsprings (suffering from haemophilia, diabetes, colourblindness, sickle cell anemia, etc. mental defects) by studying the pedigree charts of the couples. The final decision of taking a risk, however, is entirely the responsibility of the individuals concerned.

(5) By studying the chromosomes and analysing the karyotypes of persons concerned, it is possible for the genetic counsellor to predict the possibility of transmitting chromosomal abnormalities to the offsprings.

(6) Because of advancement of medical technology, the phenotype of the progeny can sometimes be predicted with certainly. The technique known as **amniocentesis** has been developed whereby a needle is inserted into the womb of a pregnant woman and some of the amniotic fluid is withdrawn. Floating in the fluid are some foetal cells, which can be cultured and studied for chromosomal abnormalities, as in families with a history of Down's syndrome. Sex abnormalities (Klinefelter and Turner's Syndromes) in the offspring can also be identified. These can be prevented by voluntary abortions. More than 30 different diseases can now be detected prenatally using amniocentesis.

(7) Suspected errors of metabolism can be identified and can be prevented by voluntary abortions.

Many countries have excellent counselling centres to advise the common man regarding various genetic disorders and prevention of their propagation.

QUESTIONS

1. Name a few of the common chromosomal abnormalities in man. Describe their chromosomal basis and their phenotypic characters.
2. What do you mean by sex-linked inheritance? Name two sex-linked characters in man. How sex-linked inheritance differs from autosomal inheritance?
3. 'A recessive mutation has more chances of expression in males than in females'. Explain how and why?
4. Explain the mechanism of sex-linked inheritance with a suitable example from man.
5. Discuss the genetics of ABO blood groups and outline the principle on which the transfusion of blood is based.
6. Discuss the various syndromes known to be due to numerical changes in chromosomes in human beings.
7. Explain Rh factor. How can a marriage between Rh⁻ female and Rh⁺ homozygous male cause erythroblastosis foetalis.
8. How and why the blood of different human beings differs? Explain in detail.
9. With the help of suitable pedigree chart, indicate the possible genotype and phenotype of the progeny of a marriage between a colourblind man and a normal woman.
10. A certain person was found to be having 47 chromosomes in his body cells instead of normal 46. Mention any three possible chromosomal abnormalities and one main symptom each associated with them in such case.
11. An Rh-negative woman should not marry an Rh positive man. State the scientific reason for it.
12. Work out the possible genotypes and phenotypes of the progeny of a marriage between:
    (i) a colourblind man and a colourblind woman.
    (ii) a haemophilic man and a carrier haemophilic woman.
    (iii) Two sickle-cell carriers.
13. What do you mean by karyotype?
14. What is banding pattern of chromosomes? What is its utility?
15. What is Rh-factor?
16. Explain the basis of sickle cell anaemia syndrome with the help of genotype outline.
17. Explain how haemolytic anaemia of new born is associated with Rh-factor.
18. What happens when an egg with XX chromosomes is fertilized with a normal sperm?
19. How do you identify Turner's syndrome?
20. Write short notes on:
    (i) Down syndrome
    (ii) Klinefelter's syndrome
    (iii) Turners's syndrome
    (iv) Barr body
    (v) Y-spots
    (vi) Sex-linked abnormalities in man
21. If a normal woman is married to a colourblind man, how many of her children will exhibit colourblindness?
22. What happens when a Rh⁻ woman bears a Rh⁺ child?
23. It is advisable for all people to know their blood groups but more so for the newly wedded couple. Comment.

24. A man has poorly developed breast, webbed neck and feminized secondary sexual characters. What abnormality does the exhibit and what is its reason?

25. A person suffering from Klinefelter's syndrome will exhibit how many barr bodies and fluorescent Y-spots?

26. Fill in the blanks:

(1) The study of inborn error of metabolism in man was introduced by................in...............

(2) The incompatibility of ABO blood groups was discovered by...................

(3) The antigens present in the blood of rhesus monkey that coagulate blood of 85% American human population is known as............

(4) The haemolytic jaundice in foetus is called.............and is caused due to incompatibility of............

(5) In human karyotype the chromosomes of a pair which are dissimilar in male and female are the...............

(6) Autosomal abnormality in man which was first reported in 1866 is called................

(7) Colourblindness in man is an example of genetic abnormality due to................

(8) The individuals of blood group O are called universal ....

(9) The clumping of blood corpuscles due to antibody reaction is called................

27. When a woman carrier for colourblindness is married to a colourblind man, what phenotypes will appear in their offsprings?

28. Name the kind of blood cancer involving white blood cells.

29. What shall be the phenotypes of F_1 generation in a cross between a colourblind man and normal heterozygous woman?

30. Name the genetic abnormality that is caused due to trisomy of the 21st pair of chromosomes in man.

31. What is the location of the gene causing haemophilia?

Socially Significant Diseases (Mental Health, Addiction)

MENTAL HEALTH

A person is mentally healthy if he is emotionally balanced. We become aware that a person is emotiomally or mentally sick when we notice change in his or her behaviour, thinking, feeling, perception and judgment. It is estimated that 1 per cent of world's population suffers from mental illness and 10 per cent from mild mental disorders.

Basically, physical health and mental health are closely associated. Physical illness, problems or every day life, anxiety, irritability, aggression, tiredness and worry may lead to *stress*. *Stress* may cause depression. In normal healthy person the response to stress is depression but they soon become normal. In abnormal person-the stress lead to prolonged *depression* and person requires medical assistance.

Types of Mental Illness

Mental illness can be discussed under following heads—psychosis, neurosis amd other disorders (epilepsy and mental retardation).

1. Psychosis—In psychosis patient loses touch with reality, is unaware of himself and his illness. The disease is caused (i) when a part of brain does not function properly (dysfunctioning) either because of some physical damage or due to such ailments as high blood pressure, diabetes and tuberculosis etc. (ii) when there is a change of balance of chemicals produced at the synapse.

(i) In *schizophernia* patients suffer from hallucinations and show withdrawal from real world.

(ii) *Affective psychosis* is a severe form of depression from which he fails to come out.

2. Neurosis — Neurosis is milder than psychosis and is psychological in origin. The patient does not lose touch with the real world but show excessive or prolonged emotional reration to a stress. This reactions includes anxiety, fear, phobia or sadness.

There is no clear cut cause of this disorder but may result from interaction of several factors like shyness, fear, dominating parents etc. The treatment includes persuading the patient to eat and attempting to loose the knot by winning patient's confidence.

3. Epilepsy—This is characterised by fits or *convulsion*. The person loses consciousness and falls down anywhere.

Causes of Mental Illness

   (i) Damage of brain portion

   (ii) Hereditary factor

   (iii) Childhood experiences

   (iv) Atmosphere at home.

   (v) Lack of affection.

   (vi) Rivalry among brothers and sisters.

Behaviour is controlled by brain. Any damage to the brain either due to injury, infection, poor blood supply, tumour in brain, excessive and prolonged use of alcohol, drugs, degenerative diseases or even nutritional deficiencies can cause mental illness.

Hunger, poverty, injustice, insecurity, cruelty, partiality and lack of opportunity are also responsible for impaired mental health.

Treatment of Mental Disorders—To divert the attention or make a person busy in some activity is one method if a person is suffering from slight depression. But if a person is suffering from psychosis or severe neurosis, he should be looked after by a medically trained psycotherapist. The treatment involves—*psychotherapy* and *chemotherapy.*

(i) **Psychotherapy** means treatment of mind.

It is a slow treatment, involving patience and care. It involves helping the patient to understand and come to terms with the patient's problems.

(ii) Drug therapy—It involves use of *tranquilizers* to slow down the brain activity in very disturbed patients. Drugs are used only in acute cases of psychosis. In recent years carefully monitored use of tranquilizers has enabled many patients to return home after many years in the mental hospitals.

Antidepressants are also used to change the mode of very depressed patients. Drug therapy shall be carried out under the supervision of a trained doctor.

(iii) Shock treatment (ECT) is used in selected cases and can produce dramatic results in severe depression.

(iv) Rehabilitation or social therapy can play a major role. Compassion and understanding by family and society can help to improve conditions of such persons and an assurance from the members of society can help the patient to come out of depression.

Attitude to Mental Health

Many people are embarassed by mental illness. The society's attitude towards such persons is not conducive. These are not accepted in the society. This hinders in their recovery. Therefore, patients' own attitudes both to himself and his illness and to the person treating him is also of great importance. Consequently doctors and nurses must cultivate the ability to reassure their patients and build up confidence.

Tobacco Smoking

Smoking is the practice of inhaling vapours of tobacco in the form of cigarettes, biris or cigars. It is practised by all groups of people, rich and poor, old and young equally and has been quite popular for the last four or five centuries. The persons have become so much addicted to smoking and the habit of smoking has become so much popular that even the warning given on cigarette packets that 'Smoking is injurious to health' has not affected the number of smokers.

(i) **Nicotine**—The tobacco smoke contains about 300 chemical compounds—including *nicotine*, carbon monoxide, hydrogen, cyanide, polycyclic aromatic hydrocarbons, irritant substances, and at least 16 substances capable of causing cancer. Nicotine is the major stimulatory component of all tobacco products. Its very small quantity in blood speeds up the activity of nervous system. It gives temporary relief to the strained nerves. But nictonine is highly poisonous. The amount of nicotine present in one cigar or above 20 cigarettes (about 0.07 gm) if injected intravenously can be fatal. Its immediate ill effect is not visible because in smoking only 10 per cent of smoke is inhaled.

Effect of Nicotine

(i)   Nicotine stimulates passage of nerve impulses.
(ii) It causes relaxation of muscles.
(iii) It causes release of adrenalin.
(iv) Increases heart beat and contraction of peripheral blood vessels leading to blood pressure, that increases risk of heart diseases.
(v)   In pregnant women nicotine causes retardation of foetus growth and reduction in weight.
(ii) **Carbon monoxide** reduces oxygen carrying capacity of blood.
(iii) **Polycyclic hydrocarbons** are carcinogenic.

Diseases Associated with Smoking

Long term effect of smoking are—

1. Lung cancer—Most serious effect of smoking is lung cancer. It is more common in persons smoking cigarettes than those smoking cigar or pipe because cigarette smokers inhale the smoke. This is because of polycyclic hydrocarbons which enter lungs along with cigarette smoke.

Mouth cancer is found in persons chewing beetle and tobacco.

2. Bronchitis—It is inflammation of bronchial tubes, particularly those leading to alveoli. The chemicals in cigarette smoke inactivate cilia that line the alveoli and thus switch off the cleaning mechanism. Failure of removal of phlegm reduces lungs gaseous exchange capacity and causes bronchitis.

3. Emphysema—Because of phlegm breathing out air from alveoli becomes difficult. This causes stretching of alveoli and fine bronchioles. Coughing weakens the wall of alveoli. This causes break down of alveoli wall reducing alveolar

surface for gaseous exchange leading to emphysema.

4. Heart diseases—Smoking increases chances of heart diseases because nicotin constricts peripheral blood vessels and increases heart rate.

5. In addition, smoking causes gastric and duodenial ulcers.

Alcohol and Alcoholism

Alcohol is consumed as beer, wine, whisky, toddy, brandy, vodka, gin or rum etc. Alcohol is rapidly absorbed by stomach wall and within no time enters blood stream.

Drinking is considered to be a social custom. Majority of people are social drinkers. But excessive drinkers are unable to control drinking and become irritant if deprived of it.

Effects of Alcohol Drinking—If taken in limited or modest amount alcohol reduced feeling of tension and inhibition, person becomes more vocal, aggressive and argumentative. However, in high doses, alcohol caused impaired judgement, slows down movement of nerve impule causing impaired muscular coordination, affects alertness and increases, time to react to an unexpected situation. It affects vision also. For these reasons it is said, 'DRIVING AND DRINKING DO NOT GO TOGETHER'. **Effects of alcohol addiction**—Alcohol addiction results in

(i) **Lowering of blood sugar level.** It may have harmful effect on brain, causing in cases permanent nerve damage.

(ii) **Liver is most affected by excessive drinking.** Liver cells synthesize fat from excess alcohol which is deposited in hepatie cells and bile passages. This impairs protein synthesis and conversion of glycogen. This leads to reduction in enzyme production and accumulation of fats and glycogen in hepatic cells. This is called '*fatty liver syndrome*'. In advanced stages it causes *liver cirrhosis* and *bilary cirrhosis*.

Amnesis or loss of memory is commonly associated with excessive alcohol intake.

Dependence on drinking is both physical and physiological. Its withdrawal symptoms leads to shakes.

Drinking has a socio-economic impact because excessive drinking or alcoholism affects the family, growth and development of children. It shall be treated as a social abuse.

Drugs Addiction

Drugs—Drugs are substances used to treat diseases or relieve symptoms. Some of the drugs are used to replace a missing substance essential for normal health (like Vitamins). Some drugs are used to combat against germs causing infection. While a third category of drugs include those substances which work on the nervous system and act either as *stimulants* to excite it or as *depressant* which slow down the activity of brain. Some may act as *sedative* and other causing *hallucination*.

Drug Addiction—The drugs belonging to third category are often used by persons regularly and become a part and parcel of their habit. The body becomes accustomed to them and may even become dependent. The addict then feels anintense urge for them, and is physically ill and distressed when deprived of them. This condition of feeling compelled to take certain drugs is known as *drug addiction*.

(i) **Tranquillisers and Depressants**—Tranquillisers slow down the high centres of brain and relieve from worries. These influence only the mental excitation but do not effect the working efficiency. Therefore, after taking a tranquilliser, a person works and behaves normally. Drugs like *Equanil, Librium* (chlor-diazapoxide), *Valium* (Diazapam), *Calmpose* and *Luminil*. If these drugs are taken regularly, a person becomes addicted to it.

Depressants are used to calm anxiety and produce sleep. These drugs produce drowsyness and a feeling of confusion. The barbiturates are used as depressants or sedatives in medical profession. Their excessive use causes addiction.

(ii) **Narcotics**—The narcotics also produce a temporary feeling of well-being and freedom from anxiety. These produce stuper and sleep and relieve pain. These include *Opium, Morphine, Codein* and *Heroin*. Narcotics induce addiction if used repeatedly. *Opium* is extracted from unripe capsules of poppy plant Morphine, coedin and Heroin are derived from opium.

(iii) **Stimulants or Antidepressants**—The stimulants are drugs that temporarily increase the mental alertness, self confidence. These are also known as *mood elevators*. Amphetamines are stimulants drugs. The users of stimulants call them '*ups*' because these give a feeling of energy. But their regular use leads to addiction and addicts may

feel severe fatigue and depression if they do not take these drugs. Coffee and tea also contain a small amount of stimulant (*caffeine*) as do some cola drinks. The stimulants are marketed under the names of **Tafrenil, Monoamine oxidase inhibitors MAOI, Tafenesin, Imipramine, and Amitriptyline.**

(iv) **Psychedelic or Vision Producing drugs**—These drugs have a strong effect on the cerebrum and sense organs and take the user to a world of fantasy giving him false and temporary happiness. The individual may sense strong colour and strong sounds even though nothing is there. These drugs include *LSD* (Lysergic acid diethylamide), *Marijuana* and *hashish*. In small doses these drugs are more like alcohol or barbiturates (*i.e.* act as depressants).

L.S.D. is the abbreviation for *D-Lysergic acid Dionethylamide*. It is one of the most dangerous drugs of the modern times derived from Argot fungus. It causes nightmares, floating sensations, horrible experience of various kinds. Its continuous use causes chronic psychosis and damage to central nervous system.

Effects of Drug Addiction

The excessive use of such drugs not only produces addiction or dependence but has multifarious effects on his physical and mental abilities.

1. Their regular use slows down reflexes and causes confusion. That is why drug addicts are more prone to accidents.

2. An overdose of some of these drugs may be fatal.

3. These drugs affect liver and digestive tract and cause general weakness and anemia.

4. LSD can even cause chromosomal abnormalities in the cell nucleus and may result in the birth of abnormal children. As for example, use of thalidomide (a tranquilizer) causes flipper-shaped limbs in the foetus.

5. Person using these drugs loses interest in future.

Reasons of Drug Addiction

There are several social, economical and other reasons which may force a person to become addicted to drugs or to alcohol.

1. **Association with drug addicts**—Most persons start the use of drugs as a result of association with those persons who already take drugs regularly.

2. **Curiosity**—Often the use of drugs is started just out of curiosity to know their feel. Constant description by friends of the good feeling by drug consumption creates a temptation and breaks the barrier in the youngsters.

3. **Family history**—If the elder persons in the family take drugs, their children also get on to that habit.

4. **Excitement and adventure**—The feeling of excitement and adventure enjoyed by the use of drugs often makes young people take to drugs.

5. **To overcome frustrations and depressions**—Certain persons take drugs to get temporary solace or relief from their personal problems and depression to forget oneself for time being.

6. Drug addiction in school children or collegiates is more often to get rid of feeling of insecurity and loneliness. Such children often do not get full affection and appreciation.

7. **Looking for different world**—Certain people presume that drugs open a new world of perception and nearness to God.

8. **Desire to do most work**—Stimulants increase efficiency and subside hunger. These are taken by persons who want to do more work day and night.

9. **Relief from pain**—Some people take drugs to get rid of pain.

However, this can be added in the end that drugs or alcohol may provide just a temporary relief from any problem but these cannot solve it. Rather the use of drugs may create more problems and may make the life more miserable.

Table 58.1 : Commonly Misused Drugs

S. No.	Type of Drug	Example	Effect
1.	Narcotic	1. Morphin 2. Heroin }	Pain killer, euphoria
2.	Stimulant	Amphetamines, benzedrine, caffeine and nicotine	Prevents sleep
3.	Sedative	Barbiturates e.g. phenobarbitone, Valium, Librium, Ethanol	Reduces tension and anxiety and promotes sleep
4.	Hallucinogens	L.S.D. and *Cannabis*	Changes perception

QUESTIONS

1. Give a brief account of drug and drug addiction.
2. How does smoking of tobacco affect diseases of the heart and lung?
3. List the various reasons leading to the consumption of drugs among the youngsters.
4. What can be the various reasons for drug addiction or alcoholism?
5. Give differences between stimulants and psychedelic drugs.
6. Discuss briefly hazards of smoking or alcoholism.
7. What are effects of smoking and drug addiction?
8. Why tea and coffee are stimulants?
9. What is the effect of use of L.S.D.?
10. Give full name of L.S.D.
11. Name the plant from which marijuana is obtained.
12. What is the source of opium?
13. Name the derivatives of opium.
14. What is the source of LSD? What harm does it cause?
15. Write a note an effects of LSD on its addict.

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Industrial Wastes, Toxicology and Pollution Related Diseases

INDUSTRIAL WASTE—TOXICOLOGY

Industrial complexes such as petrochemical complexes, oil refineries, fertilizer factories, vegetable oil plants, synthetic material plants for drugs, fibres, rubber, plastic, paper mills, textile and sugar factories, chemical factories, distillaries and blast furnaces etc. all produce a variety of pollutants. In some cases these waste are in the form of exhaust gases which pollute the air we breathe, while water soluble wastes are discharged into river or sea. Some of these water soluble pollutants are highly disastrous.

1. Air Pollutants

Air pollutants generated from the industries causes lung diseases. These are described as *industrial* or *occupational diseases*. For example,

(i) Dust, coal, stone, asbestos and china clay cause lung diseases. The diseases caused by clay sand and Sandstone grinding is called silicosis the silica particles cause irritation and then *fibrosis* and *inflammation*. It may lead to the formation of nodules or lumps of fibrous tissue.

(ii) Asbestos causes *asbastosis* which is similar to silicosis.

(iii) Oxides of sulphur (SO_2) and its hydrate, sulphuric acid in moderate concentration cause suffocation and irritation in the upper respiratory tract. Long and continuous exposure causes lung diseases like chronic asthama, bronchitis.

(iv) Carbon monoxide causes headache, dizziness, palpitation, flickering before eyes and finally it may lead to collpase, unconsciousness and even death.

(v) Persons working near mines, smelting works and refineries inhale air contamination by heavy metals. This may cause respiratory poisoning, heart diseases or damage to central nervous system.
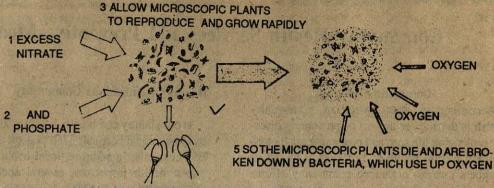
Accidental release of some toxic gases like phosgen, SO_2 etc. may cause death and respiratory and other ailments.

2. Water Pollutants

1. **Industrial effluents**—Industrial wastes are discharged in the nearby river or streams through flush-line of factories. These effluents are of different nature. These pollute our drinking water and kill oxygen producing bacteria and protists. These produce various gastro-intestinal diseases.

2. **Domestic Sewage**—It contains food wastes, synthetic detergents, human excreta and water based paints. These contaminate water and are responsible for various gastroenteric diseases and spread of cholera etc.

3. **Mineral oils** when discharged in sea, form a thick surface layer and kill marine biota.

4. Indiscriminate use of pesticides (BHC, DTT, eldrin etc.) keep on depositing in animal tissue till they reach the toxic level and are responsible for various cancerous diseases.

All these pollutants influence the normal health of human beings and thus their longeivity. These are responsible for liver diseases. Some of them may be carcinogenic; some may affect the central nervous system, while others may influence skeletal muscles causing paralysis.

3 ALLOW MICROSCOPIC PLANTS TO REPRODUCE AND GROW RAPIDLY

1 EXCESS NITRATE

2 AND PHOSPHATE

OXYGEN

OXYGEN

5 SO THE MICROSCOPIC PLANTS DIE AND ARE BROKEN DOWN BY BACTERIA, WHICH USE UP OXYGEN

4 BUT THERE ARE NOT ENOUGH MICROSCOPIC ANIMALS TO EAT THE SURPLUS PLANTS

Fig. 59.1. **Effect of Eutrophication**

3. Effect of Fertilizers

Nitrates which are very effective fertilizers producing increased yield of green crops. But even quite small quantity of nitrate taken in water over a number of years can damage haemoglobin of young children.

In lake and pond excess of nitrates and phosphate leads to *eutrophication*. This reduces free oxygen in the water.

4. Radioactivity

Some degree of radioactivity always exist in the surroundings all the time. This is known as *background radiation*. It is within the tolerance limit for both man and animals. Body has developed repair mechanism for mutations caused by background mutations so that these do not have visible adverse effect.

Higher levels of radioactivity causes some cells to divide more rapidly leading to cancer. *Leukemia* is caused by radiation. Radiations cause mutations which may lead to the birth of abnormal or deformed children.

QUESTIONS

1. Describe the effect of industrial gases on human population.
2. How does raw sewage affect river water?
3. Define eutrophication. What is its effect on pond vegetation?
4. What causes eutrophication?
5. Name a few carcinogenic fumes present in industrial exhausts.
6. Why diseases of respiratory tract have become more common now than in the olden days?
7. Define silicosis. How is it caused?

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Community Health Services and Preventive Measures

Community Health

According to PROF. WINSLOW **community health** is the science and art of preventing diseases, prolonging life span and promoting good physical and mental health and efficiency for all its members through organized community efforts. These efforts include:

1. Primary health care.
2. Awareness for general health problems.
3. Education of the individuals for personal hyiegene.
4. Sanitation of the environment.
5. Control ot community infection and

Health Organizations Community

In our country community health is looked after by Government hospitals, CGHS dispensaries and ESI hospitals. In addition, local health services, public health inspectors, several social organizations putting their best in improving the health and hugiene in India.

In 1948, the first Wrold Health Assembly met in Geneva to tackle health problems at international level. Its head quarters is known as World Health Organization (WHO). Its activities are organized under following heads:

Table 60.1 : Basic Activities of Health Centres

I. Medical Care
- (a) Treatment and hospitalization of sick persons.
- (b) Refer for specialised treatment in other hospitals.
- (c) Provision of local health services.

II. Health Education
- (a) Through personal contact—Public health inspectors or social workers.
- (b) Through audio-visual and printed media.

III. Collection and Cross-checking of Vital Statistics

IV. Environmental Sanitation
- (a) Safe germ free water supply.
- (b) Waste disposal through compost pits, soak pits, kitchen gardens, latrines and smokeless chullah.
- (c) Prevention of breeding of insect vectors.
- (d) Prevention of air pollution.

V. Prevention and Control of Communicable Diseases
- (a) Vaccination against whooping cough, diphtheria, tuberculosis, tetanus, polio, and cholera.
- (b) Eradication of Malaria.
- (c) Control of leprosy, trachoma and other communicable diseases.
- (d) Supervision of food and milk trade.

VI. Maternal and Child Health and Family Planning
- (a) Routine examination of pregnant mothers.
- (b) Delivery of child, infant and post-natal care.
- (c) Prophylaxis against anaemia and vitamin deficiency.
- (d) Visits and immunisation.
- (e) Family planning advice and services.

VII. Rehabilitation of Drug addicts and Alcoholics

VIII. Nutritional Education
- (a) Through personal contact.
- (b) Through audio-visual media.

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check the spread of epidemics.
6. Provision of efficient medical and nursing services with facilities for hospitalization and early detection of diseases.
7. Rehabilitation of alcoholics, drug-addicts and psychic and neuretic persons.
8. Maternal and child care and family planning.
9. School health services.
10. National programmes for malaria eradication, leprosy control and prevention of blindness.

1. Education and Training—to develop conciousness about good health.
2. Public Health Services-to coordinate maternal and child health and nursing etc.
3. Communicable diseases
4. Malaria Control
5. Environmental Health
6. Health Statistics

WHO works in close association with FAO (Food and Agricultural Organization) in planning food production programmes in countries where undernourishment undermines communicty health.

In 1974, WHO officially launched global immunisation programme . for children to protect them against six preventable diseases. These are diphitheria, whooping cough (pertussis), tetanus, polio, tuberculosis and measlas. In India, Immunization Programme was launched in 1985. The normal immunisation schedule is given in the Table 60.2.

Table 60.2: National Immunisation schedule	
Age	Vaccinations
3-12 months	DPT—3 doses at intervals of 4-6 weeks. Polio (oral)—3 doses at intervals of 4-6 weeks.
9-15	Measles vaccine—one dose
18-24months	DPT—booster dose Polio (oral) booster dose
5-6 years	DT (bivalent vaccine) against diphtheria and tetanus—booster dose Typhoid vaccine—2 doses at an interval of 1-2 months
10 years	Tetanus toxoid—booster dose Typhoid vaccine—booster dose
16 years	Tetanus toxoid—booster dose Typhoid vaccine—booster dose
Mothers (during pregnancy)	(a) Immunised Previously: One booster dose of tetanus toxoid, preferably 4 weeks before the expected date of delivery. (b) Non-immunised Two doses of tetanus toxoid, the first dose between 16 and 24 weeks and the second dose between 24 and 32 weeks of pregnancy.

General Preventive Measures

The general preventive measures to avoid spread of contageous diseases include—

1. Vaccination

The most important method to prevent the spread of disease germs (viruses or bacteria) is to make person immune to the infection by injecting a vaccine. The process is called **vaccination.**

A **vaccine** possesses germs in dead, weakened or virulent form of the germ or else contain their modified toxins. This when introduced into the blood of a healthy person it produces immunity to that particular disease. This process of developing resistance or immunity is known as **immunization.**

At present vaccines for smallpox, measles, diphtheria, tetanus, typhoid, cholera, yellow fever, whooping cough and polio, tuberculosis, rubella (German measles) and rabies are available.

2. Sanitation

Unhygienic surroundings are the breeding grounds for disease causing germs. It is, therefore, necessary to take proper care for maintaining cleanliness in the surroundings. *Garbage* should not be dumped on the roadside or near the inhabitated sites. There should be proper *disposal of sewage* which is often released into rivers or the sea. The sewage may contain germs of many diseases may contaminate our water source. It is, therefore, essential that the sewage should be treated with proper chemicals before being released or dumped into the water source. The treatment is done with chlorine or bleaching powder. It means only treated water should be supplied for the use in drinking and cooking. Human and animal faeces should not be left open in the nearby places. Persons should be strictly checked to spit on the roadside. Open public latrines should not be there.

3. Sterilization

Sterilization is making an object or a thing germ free by killing them using dry heat, boiling in water or exposing them to steam under pressure. Most bacteria and disease causing germs die if heated above 100°C. The sterilization may be achieved by treating the object or material with disinfectant (the chemical solutions). The process of pasteurization is used for making milk germ free.

Operation instruments, linen, cotton, injection syringe are all sterilized either by boiling them in water or putting them in autoclave. During the outbreak of cholera, jaundice etc. water is sterilized by boiling. Larger bodies of water—ponds, lakes wells etc. are made disinfected by putting some potassium permangnate.

4. Disinfectants

Disinfectants are chemicals that are used to destroy germs. These are similar to antiseptics but stronger in action so that these cannot be used on living tissues. These include *phenyle, cresol, bleaching powder* etc. These are used on nonliving materials like instruments, floor, bathrooms, operation theatres etc. to make them germ free. Concentrated solution of disinfectants is poisonous and be kept beyond the reach of children.

5. Antiseptics

Chemical substances like *carbolic acid, Dettol, Savlon, Listerine, Lysol* etc., are used on living tissue to kill the germs present. They either kill the microorganisms or slow down their growth. These substances are used as liquid in cleaning the wounds or cuts to make the germ free or as antiseptic creams which cover the surface of wounds and protect them against infection. The antiseptic techniques were introduced by SIR JOSEPH LISTER in Britain in 1860 by using carbolic acid to clean operation theatre and instruments. Prior to the use of antiseptic, disinfectants or sterilization the surgery was a horrible affair because most persons used to die after operation because in majority of cases the wound or cut used to get infected with germs.

QUESTIONS

1. What do you understand by community health? Name the preventive measures taken at Government level to prevent the spread of communicable diseases.
2. Discuss the statement 'Prevention is better than cure' in the light of community health concept.
3. Summarise important general preventive measures against communicable diseases.
4. What is vaccination ? What is the relationship between vaccination and immunization?
5. What is the use of sterilization?
6. Define the following terms:—
   (i) Disinfectants (ii) Insecticides (iii) Antiseptics (iv) Immunization.
7. Name the discoverer of vaccine. How he was able to discover it?
8. Who introduced the idea of use of antiseptics?
9. What precaution should be taken for protection of eardrum if there is sudden loud noise?
10. Summarize the steps that should be taken to protect eyes against any injury or from foreign particles.
11. List any three important steps for controlling communicable diseases.

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Biomedical Engineering
(Technology for Medical Applications)

INTRODUCTION

The conventional methods available for the diagnosis of different diseases include some simple instruments like thermometer, stethscope, sphygmo-manometer; some simple biochemical tests to determine the presence of abnormal constituents in urine, blood or body fluid, or to determine the number of different types of blood corpuscles. However, within last four decades, there had been revolution in biomedical technology. Table 61.1 shows the vast range of instruments and equipments available to be used for diagnostic purposes, treatment of diseases, and

BIOMEDICAL TECHNOLOGY

for monitoring patient's condition.

Biomedical engineering has helped human population to overcome a large number of sufferings. The contributions include—

1. **Prosthetic devices**—for physically handicapped persons
2. **Diagnostic instruments**
3. **Imaging instruments**
4. **Therapeutic instruments**

Table 61.1: List of Technology available for medical applications

Instrumentation

Diagnostic Instruments	Category
B.P. Apparatus Doppler blood flow monito	Fluid dynamics
Electrocardiograph (ECG), Electromyograph (EMG), Electroencephalograph (EEG)	Bioelectricity
Autoanalysesrs	Biochemistry Hematology

Imaging Instruments

Computerised Tomographic Scan (CT Scan).	X-ray
Endoscopes	Optical
Nuclear Magnetic Resonance Magnetoencephalography (MET)	
Radio-nucleide	Nuclear
Echocardiograph	Ultrasound

Therapeutic Instruments

Defibrillators Pacemakers	Stimulators
Medical Lasers Radiotherapy units	Radiation
Heart Assist devices (e.g. Intra-aortic balloon pump)	Organ assist
Devices	Examples
Implants	Hip joint, Heart valve Eye lens, Vascular graft.

Fig. 61.1 Biomedical instruments

(Otoscope labels: LIGHT, SPECULUM IS PLACED IN PATIENT'S EAR, SWITCH, LENS AND VEIWING APERTURE, BATTERY CASE AND HANDLE)

(Ophthalmoscope labels: LENS AND LIGHT, SWITCH, DISC FOR CHANGING LENSES)

(Sphygmomanometer labels: SCALE FOR READING PRESSURE, COLUMN OF MERCURY, BULB FOR PUMPING AIR INTO ARM-CUFF TO COMPRESS THE ARTERIES, CUFF IS WRAPPED ROUND PATIENT'S AHM DAND INFLATED)

Diagnostic Instruments	Category
Disposables	Oxygenator, Blood bag, Blood dislyser
External Prosthesis	Artificial limbs, Dentures.
Biotechnology applications Diagnostic kits Hormones, enzymes by recombinent DNA technique, cryopreserved organs and tissues for transplant	

Prosthesis

Prosthesis is artificial substitute for any part of the body which enables thousands of physically handicapped persons to live a descent and productive life. **Prosthetic devices** range from dentures to artificial eyes, nose, arms and legs. Best examples are leg and arm prosthesis. Prosthetic hands enable a person to perform simple or heavy tasks, while with prosthetic legs a person can walk unaided.

Most limbs prosthesis are passive and the artificial hand or arm is moved by the muscles of remaining stump by shrugging movement. Advances in this field include designing such limbs that are powered by compressed gas or by electricity. The 'myoelectrical arm' would enable the patient to control the movement of wrist and hand and even of fingers.

Prosthetic devices may also be attached or inserted under the skin. Prosthetic ears and noses are moulded and coloured to match perfectly with the face.

Designing artificial limbs requires proper understanding of biomechanics of normal limb, the choice of material and engineering a proper design. Dr P.K. Sethi of Jaipur has achieved a remarkable success in manufacturing artificial limb under the name **'Jaipur Foot'**. It resembles a natural foot, can withstand a vertical load of about 2 tonnes. It is light and offers desirable range of movement in all directions. It is prepared from solid rubber and aluminium.

Jaipur limb in popular is several countries like Pakistan, Sri Lanka, Indonesia, Thailand and Zimbabwe.

Cryopreservation of Tissues and Organs and Their Transplant

Man-made synthetic tissue-organs are no match for natural tissue. Therefore, in recent years, surgeons have devised transplant procedure to replace a diseased or damaged organ by a healthy one. This is called **Transplantation.**

This includes grafts of certain issues or transplantation of a complete organ. The best known examples are corneat graft, graft of skin, blood vessels, heart valves and bone. Cornea transplant has proved exceedingly successful because cornea can be preserved and stored and does not link up with blood supply and immune system.

The examples of organ transplant are kidneys, liver and heart. These vital organs need preservation. So far, these can be preserved only for a few hours at 4°C. Intensive research is in progress for prolonged storage of vital organs without impairing their functions. The preservation of organs is called **cryopreservation.** Once success is obtained in this field, it will promise the availability of spare organs or spare parts for human beings, who have diseased organ or have lost some vital part due to some accident.

(A) DIAGNOSTIC INSTRUMENTS
1. Electrocardiograph
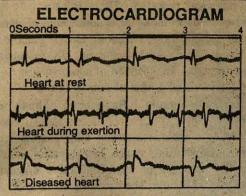
Electrocardiograph is a sensitive instrument that records the electric impulses produced by cardiac muscles of different heart chambers during cardiac cycle. Electrodes connected to the appratus are taped to the body over heart and usually on both arms and a leg. These detect the tiny electric impulses that cardiac muscles produce. The impulses are amplified by electrocardiograph which produce a tracing on a sheet of graph paper. This tracing is called **electrocardiogram (ECG).** It indicates the rate and rhythm of heart and the condition of heart muscles inferring whether heart is healthy or damaged and to what extent.

Slight irregularities in ECG indicates the presence of a cardiac disease. More serious changes on the graph reflect that the patient is suffering from **congenital heart disease, coronary thrombosis** or **rheumatic heart.**

First time, EINTHOVEN had used a string galvanometer to record human ECG.

2. Electroencephalograph
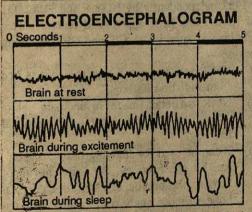
This instrument is used to record the spontaneous electrical activity of brain. Electrodes are taped to the scalp at different places. These pick up minute electrical waves generated in the nerve cells

ELECTROCARDIOGRAM

A doctor can learn much about the health of a patient's heart by taking an electrocardiogram, a tracing which records the electrical activity in the heart muscle. For example, any increase in size of one of the heart's chambers causes a change in the shape of the electrocardiogram.

Fig. 61.2

of the brain. The electroencephalograph amplifies and records, these waves on a paper as **electroencephalogram** (EEG). The shape of the tracing depends on the mental activity of patient.

ELECTROENCEPHALOGRAM

The electrical activity of the brain can be studied by electrodes taped to the skull, and recorded on an electroencephalogram. The shape of the tracing depends on the mental activity of the patient, and changes from the normal pattern can reveal disorders such as epilepsy.

Fig. 6.13

EEG helps on the diagnosis of epilepsy, brain tumour, brain infections, metabolic and drug effects on the brain and the degeneration of brain tissue etc. In future the electroencephalograph may be used for medically establishing death in case of the patient's heart is still breathing but the EEG is flat.

EEG of man was recorded for the first time by HANS BERGER about 60 years ago. Computer EEG technology has helped in the study of **evoked potential (EPS)** in which the synchronous responses to various sensory stimuli like light, sound and touch are displayed by summation and averaging techniques. The study of EPS has enabled scientists (i) to evaluate sensory and neural functions, (ii) to detect clinically silent lesions in sensory pathways and (iii) to study hearing and vision in very small children.

With the development of **Super conducting quantum interference of device (SQUID)** doctors can study weaker magnetic fields from the brain. This new technology is called **magnetoencephalography (MET)** promises to be an important investigatory tool in the study of brain functioning.

3. Autoanalyser

Computer-controlled autoanalysers are fully automated. These are used to estimate the percentage of biochemical substances like glucose, cholesterol, urea, enzymes, proteins in the body fluid, in urine or in blood. A microprocessor associated with the autoanalyser supervises the volume of samples, reagents, the temperature and timings of various steps.

The computed results checked against the control parameter are printed out. Multichannel analysers can select any type of analysis for any one of the set of samples.

(B) IMAGING INSTRUMENTS

1. X-Rays

Use of X-rays for the diagnosis and treatment of diseases was the first step in image forming technology. It is called **radiolog**. It began with the discovery of X-rays by WILLIAM ROENTGEN.

X-ray pictures of internal organs are used to diagnose diseases like pulmonary tuberculosis, pneumonia, stomach ulcers, intestinal obstructions and enlargent of heart. These are used in locating broken and diseased bones, dental caries and in detecting stone in kidney and gall bladder. The use of X-rays to take photographs is called **radiography.**

Hard tissues such as bones show up on an ordinary X-ray photography. But internal organs such as gall bladder and kidneys are made to show

up the details by injecting special radio substances into patients blood stream. Barium meal, either swallowed or injected as an enema, shows oesophagus, stomach or intestine on an X-ray plate and helps in the detection of ulcers and other disorders of gastrointestinal tract. Radio opaque fluids are injected into blood vessels for detecting any blockage (angiography)

X-ray imaging has limitations because

(i) The differentiation of soft tissue structures is not sufficient.

(ii) There is superposition of structures from front to back on the image.

2. Fluorescopy

A **fluoroscope** is similar to an X-ray machine except that instead of taking still photographs of X-rayed organ. The organ is viewed directly and continuously on a fluorescent screen similar to a television picture tube. A picture can be taken from time to time for a record that can be studied later by a surgical team to assess the necesity of surgery.

3. Computed Tomographic Scanning (CT)

CT scanning is modified X-ray imaging. It does not form the image directly on the photographic film as in X-rays but a computer reconstructs the image of organs or parts seen. It uses X-rays.

CT scanning is used in the diagnosis of diseases of brain, spinal cord, chest and abdomen. It helps in detecting tumours and monitoring the extent of their spread to neighbouring tissues and organs. It also helps in determining the feasibility of operation and in assessing the results of treatment.

3. Position Emission Tomographic Scanning (PET)

In this method, positron emitting radio-isotopes like ^{11}C, N^{13}, O^{15} and F^{18} are used in place of X-rays as the illuminating agents. These are generated by cyclotron. These molecules are incorporated into the biological molecules such as glucose, amino acids, carbon dioxide and ammonia. These positron emiting biological compounds are then injected in very small quantity into the body or are inhaled by the human subjects. These radioactive compounds are called **tracers**. The three dimensional distribution of these labelled tracers is probed by PET cameras. The images are constructed by a computer.

Thus positron emission tropographic scanning produces images which provide quantitative regional information on metobolic and physiological processes. These images help in studying and measuring the regional cerebeal blood volume, blood flow, metabolic rate of glucose.

Using PET imaging technique, UK Scientists have foreseen. The location of *colour processing* centres in visual cortex of human brain.

4. Nuclear-Magnetic Resonance Imaging (NMR)

In this technique a strong magnetic field is acquired by using either large water cooled resistive magnets or superconductive magnets using liquid helium. The patient is made to lie in the centre of magnetic ring along the axis of magnetic field. The external magnetic field causes generation of magnetic resonance by the nuclei of hydrogen arms present in the biological tissues. The signals generated in the process are called **nuclear-magnetic resonance signals** or **NMR-signals.**

These NMR-signals are picked up by a receiver coil, are converted to digital signals and are fed to a computer which reconstructs the image in the same manner as in CT and PET scanning.
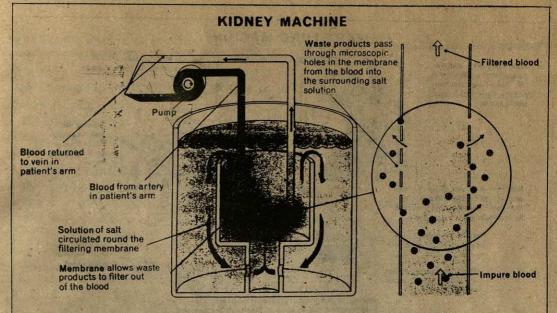
The process of NMR imaging was discovered in 1952 independently by BLOCH and PURCELL, but its use has been appreciated recently. This technique is superior to CT and PET scanning because—

(i) NMR does not use X-rays and thus is free from radiation hazards.

(ii) NMR can obtain images in any plane unlike CT which can give only cross sectional imaging.

(iii) It can be used for studying tissue metabolism by spectroscopy. By using nuclei of carbon, phosphorus, and sodium etc. metabolic activities can be documented at the tissues level.

5. Ultrasound Imaging (Sonography)

In this type of imaging ultrasound waves are produced a phenomenon called **piezoelectric effect.** When an electric potential is applied to some crystals like **lead-zirconate,** they become excited and vibrate. These vibrations produce ultra sound waves.

Ultrasonic waves pass unimpeded through a homogenous tissue. But when these come in contact with another tissue or organ, either the whole ultrasonic wave or a part of it is reflected and received back by the same crystal and is

Waste products pass through microscopic holes in the membrane from the blood into the surrounding salt solution

Filtered blood

Pump

Blood returned to vein in patient's arm

Blood from artery in patient's arm

Solution of salt circulated round the filtering membrane

Membrane allows waste products to filter out of the blood

Impure blood

A patient whose kidneys have failed can be kept alive by the regular use of a kidney machine, which cleanses his blood of waste products by copying the action of a natural kidney. Blood pumped from an artery in the arm of the patient passes over a thin plastic membrane in a bath of circulating saline solution. Water and waste products such as urea pass through microscopic holes in the membrane into the surrounding solution, leaving the much larger blood cells behind. The purified blood is then warmed to blood heat and pumped back into a vein in the patient's arm. Using this machine, patients with chronic kidney failure have survived for more than 12 years. However, they are usually advised to have kidney transplant operations, if suitable donors are available.

Fig. 6.14

converted into an electric signal. This signal represents the reflecting interface and is shown on the oscilloscope as a deflection from the base-line.

Ultrasound imaging has replaced X-ray imaging because it is free from radiation hazards in urban areas. However X-ray technology is still in use in India because it is much less expensive than other techniques described here.

(C) THERAPEUTIC INSTRUMENTS

1. Laser Therapy

Lasers are high energy particles of light, amplified by stimulated emission of radiation. These are used as powerful energy beams and can be specifically targetted to any kind of tissue. Laser therapy is being used as a substitute for surgical operations to treat some tumours such as retinal tumours, brain tumours and tumours in other parts of the body.

The tumours within the tissue or organ is localised by X-ray or ultrasound. A sharp and powerful beam is then focussed on the tumour cells. The cells are thus selectively burnt out without damaging the normal cells.

By using different sources of element or compounds, different types of lasers can be generated. Some of the known lasers are Argon laser, Neon laser and carbon dioxide laser.

Laser Photo-bleaching is used to follow the fate of a hormone bound to some specific receptors on the cel surface. This helps in understanding the mechanisn of hormone action.

2. Kidney Machine or Dialyser

A patient whose kidneys have failed can be kept alive by *dialysis*. The kidney machine has a semipermeable plastic membrane—a thin skin containing minute pores. These allow water and waste products to pass through but are small enough to retain back blood cells and proteins.

The patient is connected to the kidney machine by tubes inserted in blood vessels in his arm or
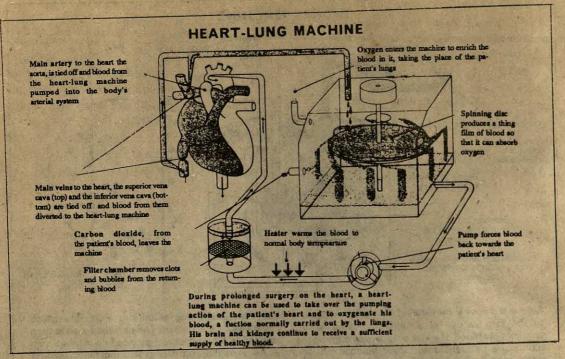
HEART-LUNG MACHINE

Main artery to the heart the aorta, is tied off and blood from the heart-lung machine pumped into the body's arterial system

Oxygen enters the machine to enrich the blood in it, taking the place of the patient's lungs

Spinning disc produces a thing film of blood so that it can absorb oxygen

Main veins to the heart, the superior vena cava (top) and the inferior vena cava (bottom) are tied off and blood from them diverted to the heart-lung machine

Carbon dioxide, from the patient's blood, leaves the machine

Heater warms the blood to normal body temperature

Pump forces blood back towards the patient's heart

Filter chamber removes clots and bubbles from the returning blood

During prolonged surgery on the heart, a heart-lung machine can be used to take over the pumping action of the patient's heart and to oxygenate his blood, a fuction normally carried out by the lungs. His brain and kidneys continue to receive a sufficient supply of healthy blood.

Fig. 64.5

leg. The blood of patient passes through the kidney machine and is filtered.

3. Intra-aortic Balloon Pump

In some heart diseases pumping action of cardiac venticle becomes too poor to maintain effective supply of blood to tissues and organs. The use of intra-aortic balloon pump assists the ventricle by increasing the blood supply to its cardiac muscles and enhancing the contraction power.

It consists of a special **balloon** positioned in the descending thoracic aorta. It is connected to an external machine which inflates and deflates the balloon rhythmically with helium. When balloon inflates during diastole (when ventricles are in relaxation phase), more blood is pumped into the coronary arteries, that supplies blood to heart muscles. Balloon deflates during symbol (when ventricles are contracted) removing impedance.

4. Pacemakers

When the heart rate drops to an abnormally low level like 30-40 instead of normal 72-80 beats per minute, **pacemaker** is used to restore normal heart beat. The use of artificial pacemaker to pace the heart was interoduced by CHARDACK in 1960.

A **pacemaker system** consists of a pulse generator and an electrode. The *pulse generator* is a sealed box. It encloses (i) *lithium cells* for providing power for over 10 years and (ii) *an electronic* circuit regulates the rate, pulse, width etc of the electric impulse.

5. Heart-Lung Machine

This machine takes over the functions of heart and lungs, keeping the circulation going. It maintains balance of oxygen and carbon dioxide in the blood. It is used during prolonged cardiac surgery.

The electrode is a fine metallic spring ensheathed with a thin covering of biocompatible plastic. It is inserted into the right ventricle through a vein in the neck so that its tip lies in contact with the interior of right ventricle. Its other end is connected to the pulse generator which is placed under the skin below collar bone.

Implants

Implants are artificially prepared parts or devices used for replacing a diseased organ or tissue within the body. These include replacement of joints, arteriers, heart valves etc. The implants must be nontoxic and biocompatible.

1. Artificial Heart Valve

Valves separating the auricles and ventricles or ventricle and aorta may become severely damaged

by rheumatic fever or other diseases and fail to open or close fully. These defective valves are replaced by artificial valves. Valve replacement is done all over the world and there are about 16 centres in India carrying out this operation.

The artificial valves are fabricated either from plastic, metal alloys and ceramic (*mechanical valves*) or from cadavers or pigs (*tissue values*) or are fashioned from pericardium of animals.

The mechanical valves are durables but the patient is obliged to take medicines to reduce clotting of blood. The tissue valves do not require the use of anticoagulant by the patient but the valves tend to calcify.

2. Vascular Grafts (Artificial Arteries)

Walls of arteries usually get thickened with advancing age (*anterosclerosis*) or due to some vascular diseases, the blood vessels become narrow, or their lumen is blocked or occluded. This reduces blood supply to the heart muscles and organs of vital importance. Due to inadequate supply of oxygen and nutrients the organs starve and may lead to cardiac arrest. In some cases segments of arteries may dilate like balloons (*aneurysm*) and rupture with fatal consequences like brain haemorrhage.

In both occlusions and aneurysms the defective segments of arteries are either replaced or an alternative root is fabricated by using artificial arteries as vascular grafts.

The tubular grafts of porous plastic fibres of dacron and teflon are used as excellent arterial substitutes.

DIAGNOSTIC KITS

Many of the diseases and abnormal or malfunctioning of certain organs can be detected by utilizing ready to use kits. These diagnostic kits include for—

1. **Parasitic diseases like malaria, hepatitis, taeniasis (Taenia infection).**
2. Detection of pregnancy.
3. Checking sensitivity allergens.
4. Detection and estimation of various substances in blood.
5. Detection of cancer.

Detection techniques are based on (i) either recombinant DNA methods or (ii) immunological methods employing specific antibodies.

The parasite detecting diagnostic kit consists of a specific monoclonal or polyclonal antibody raised against the antigen or antigens of the parasite. The monoclonal antibody technique helps in correct diagnosis of the disease in such cases where symptoms are unambiguous or a variety of parasitic infections produce symptoms.

QUESTIONS

1. Explain the medical uses of lasers.
2. Describe various uses of X-ray photography and its modification in the diagnosis and treatment of diseases in human beings
3. Differentiate in the uses and functioning of X-ray imaging, and CT and PET scanning.
4. Why X-ray use is becoming limited and is being replaced by ultrasound imaging?
5. What do you mean by cryopreservation of tissues and organs?
6. Differentiate between implants and transplants?
7. Describe various types of artificial heart valves.
8. Give full names of the following:
   (i) NMR (ii) CT
   (iii) EEG (iv) ECG
   (v) PET (vi) SQUID
9. Discuss the functioning of electrocardiograph. What is its use in medical diagnosis?
10. How ultrasound waves are used in medical diagnosis?
11. What will you use for the proper diagnosis of following cases:
    (i) a man is suffering from some brain infection.
    (ii) a person has a fracture bone
    (iii) a person is suffering from lung cancer
    (iv) to test and confirm pregnancy.
12. Describe the necessity of intra-aortic balloon therapy.
13. Describe uses of an autoanalyzer.
14. Describe structure and utility of a pacemaker.

15. What is the difference between prosthesis and implant.
16. What do you understand by cosmatic surgery?
17. What is principle of blood dialyser?
18. Fill in the blanks:
    (i) Tissue values for implanting in human heart are fashioned from ....of animals.
    (ii) EEG was recorded for the first time by..................
    (iii) Radio-isotopes emit......................on radioactive decay.
    (iv) An........................opaque material is used before X-raying hollow organs.
    (v) Positrons are....................charged particles.
    (vi) Crystals of......................are used to produce ultrasonic waves in ultrasound.
    (vii) Pacemaker is used only when heart beat of the patient falls to.................... .

□ □

CHAPTER 62

Growth of Human Population

History of man is only about 50,000 years old. In the course of human history there have been three major population explosions, each corresponding to a major change in the environment—the first population explosion, occurring about 20,000 years ago. It was brought about by the use of tools that allowed improvement in hunting and food gathering methods. The second revolution occurred about 6,000 years ago, and was brought by improvements in farming. The third revolution was brought about 300 years ago and was caused by improvement in food production, industry and medicine.

The present rate of growth of human population is estimated to be 2% per annum. The world population in 1990 is expected to be 5 billion people and by the end of this century it will be 6.35 billion.

TABLE 62.1: WORLD POPULATION

Year	Population
1850	1 billion
1925	2 billion
1965	3 billion
1980	4 billion
1990	5 billion
2000	6.35 billion

If the present growth rate is maintained it is stated that only one square foot of the earth surface will be available per one person within the next 700 years.

CONCEPTS OF BIOTIC POTENTIAL, ENVIRONMENTAL RESISTANCE AND CARRYING CAPACITY

Biotic Potential—The physiological capacity to produce offspring is known as **biotic potential or reproductive potential**.

Environmental Resistance—The biotic potential of organisms is enormous but all the offsprings do not survive owing to shortage of food, diseases and predation. These factors which check the population growth are called *environmental resistance*.

When the number of individuals added to the population equals the number of individuals lost, the population remains constant. This is called *zero population growth*.

Patterns of Population Growth

Population shows an increase when the number of births exceeds the number of deaths. When the environmental factors are favourable, the population shows *exponential growth*. When plotted on a graph the growth curve assumes the shape of the letter 'J' and is termed as the *J-shaped growth curve*. But this does not happen in nature as the environmental resistance does not allow a population to grow towards infinity.

S-shaped or Sigmoid Curve

When a species is introduced into a new habitat where there is no shortage of food, its population multiplies rapidly. This is called *exponential growth phase*. This phase represents the maximum growth rate as there is no environmental resistance. After a while the individual becomes so numerous that further multiplication is checked by the factors of environmental resistance. At this stage the birth and death rate exactly balance each other. At this stage the population growth reaches to zero. This is the *plateau phase* and resulting growth curve is *S-shaped* or *sigmoid growth curve*.

Carraying capacity—An environment can carry only a limited size of population. This limit is represented by a constnat K and is termed carrying capacity. Thus carrying capacity is the max-
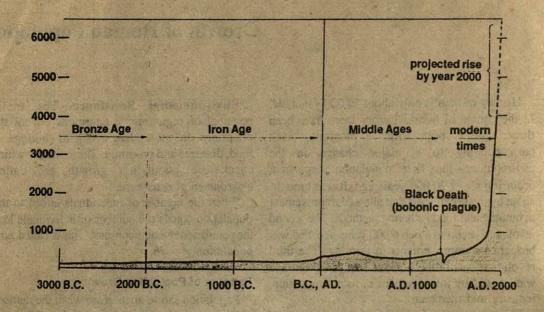
Fig. 62.1 Growth of world population

imum number of individuals which can envrionment can support. Generally populations stabilizes around the carraying capacity.

Causes of Increase in Human Population

According to *Malthus* in his 'Essay on Population' when unchecked, population increases in a geometric ratio while food supply increases in arithmetic ratio. Beyond a certain limit the population experiences acute food shortage and a large number of individuals die of starvation malnutrition. Following reasons are attributed to the increase in human population:

1. Increase in food production due to advances in science and technology.
2. Infrequent deaths from famine now than four decades ago.

However, endemic hunger and chronic undernourishment are a regular cause of deaths in the countries of South Asia, Latin America and parts of Africa.

3. Increase in life expectancy at birth due to better public health care and greater

medical attention.

4. Eradication of fatal epidemic diseases through major community health programmes.

It can be concluded that human population has increased due to (i) decline in death rate and (ii) an increase in longevity.

Consequences of Population Explosion

Population explosion has become a serious world concern. The continuous population growth will result in misery, poor health and increase of urban slums due to following reasons:

1. It will lead to food crisis resulting in famines, hunger and poor health.
2. There will be acute shortage of clothing and shelter.
3. Shortage of drinking water.
4. Pollution of air, water and land.
5. Danger of epidemic diseases.
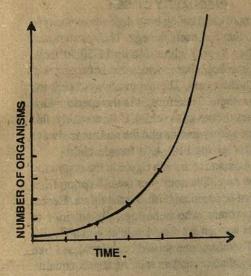6. Unemployment, shortage of raw materials, housing and lack of educational

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Fig. 62.2 The exponential growth curve of J-shaped curve

POPULATION ACCELERATION | POPULATION GROWTH EXPONENTIALLY | POPULATION GROWTH DECELERATING | POPULATION CONSTANT

K

BIRTH RATE & DEATH RATE BALANCE EACH OTHER MAINTAINING EQUILIBRIUM

ENVIRONMENTAL RESISTANCE INCREASES DEATH RATE OR DECREASES BIRTH RATE

POPULATION GROWTH SLOWS AS REPRODUCTION GETS UNDERWAY BECAUSE OF SHORTAGE OF REPRODUCTIVE INDIVIDUALS

MAXIMUM GROWTH RATE UNDER OPTIMAL ENVIRONMENTAL CONDITIONS— NO ENVIRONMENTAL RESISTANCE
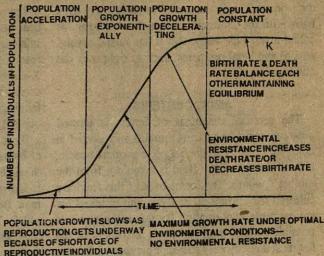
Fig. 62.3 S-Shaped or sigmoid population growth curve characteristic of many species when introduced into a favourable environment K = carrying capacity.

facilities.

7. Acute shortage of natural resources.

Population Control

Population growth can be checked through (1) family planning and (2) mass media.

Family Planning

Efficient, cheap, safe, reversible and acceptable methods should be employed for birth control. Following are the scientific methods for birth control:

1. By taking oral contraceptive pills. These pills surpress the pregnancy by suppressing the production of ovum by hormones.

2. Following are the methods to prevent fertilisation of ovum by sperm—

(i) Use of intra-uterine contraceptive devices (IUCD) like the copper Torloop.

(ii) Use of condoms, diaphragm or spermi-cidal cream.

(iii) *Vascotomy i.e.* cutting of spermatic ducts in male and *tuberctomy i.e.* cutting of fallopian tubes in females.

The government has opened family welfare and dispensaries to provide necessary help for birth control.

2. Mass Media or Communication

Radio, television, newspapers, magazines, hoardings and posters should be employed to spread the message of family planning and birth control and its advantages.

The future of mankind depends on stabilisation of human population at a level that ensures basic necessities of life, employment and happiness.

TEST TUBE BABIES

Thousands of married couples are unhappy as they are not able to get children. Now biomedical application and services are available for such

couples.

Some women are not able to have a normal conception. It is possible now to remove the ova of such a woman under aseptic conditions. This ova is fertilised by the sperm of her husband and the fertilised egg is maintained in vitro till the 32-cell stage. Now it is planted in the uterus of the woman. The mother can give birth to a normal baby with the professional help. Such a baby is called a *test tube baby*. But it has raised several ethical and legal problems, such as right over the child.

AMINOCENTESIS

The prenatal diagnosis of foetus is termed *amniocentesis*. The foetus remains surrounded in amniotic fluid. With the help of a surgical needle, a small sample of the fluid is taken out from the mother's womb. The foetal cells of this fluid are cultured for chromosal analysis and checked for any possible abnormality. By this technique it is possible to look into metabolic disorders in the foetus at the very easy stages of pregnancy. In case of a serious, incurable congenital defects, the pregnancy may be terminated.

Amniocentesis has been presently misued. Since with its help it is early to establish the sex of foetuses, female foetuses have been ruthlessly destroyed.

INEQUALITY OF SEX

The sex of child taking birth depends on the type of sperm that fertilisers the egg. The spermatozoa bear either X or Y chromosome in 50:50 ratio. Infact it is a sheer chance which kind of sperm will fuse with the ovum. The ovum always bears the X-chromosome. Therefore, it is the sperm which determines the sex of the child. Unfortunately, this fact is not widely known and the mother is always blamed for giving birth to a female child.

Thus woman is the main figure in the continuity of human race. She nourishes the off-spring from the time of conception, birth and the infant. Hence, it is the woman who is biologically superior to man. But women are meted unjustice in all walks of life. Therefore, one should be rational and free from prejudice in matters relating to sex equality to women.

QUESTIONS

1. What is a population growth curve? Draw two growth curves known to you.
2. Explain the following:
   (i) Carraying capacity
   (ii) Biotic potential
   (iii) Environmental resistance to population growth.
3. What are the limiting factors which prevent earth from supporting a human population of indefinite size?
4. Can the problem of growing population be solved for ever by increasing the food problem? Explain?
5. What do you understand by the term 'Population Explosion'? What are the causes for population explosion.
6. Mention the different methods of birth control.
7. What are test tube babies?
8. Describe a technique by which genetics disorders in the developing foetus can be detected.

FUTURE OF BIOLOGY

Progress in science in the past four decades has been remarkable. The achievements during this period have been much greater than in the past four centuries. A large number of science fictions have been turned into reality, though some possibilities have remained refractory.

Biologists have successfully achieved :

1. Improvement of quality of life for humans.
2. Improvement of quality of food plants to provide food for the ever-increasing population.
3. Hybridisation of cattle and sheep etc. to ensure higher production of milk and meat.
4. Birth of test tube babies.
5. Improvement of germplasm by genetic engineering and somatic hybridisation.
6. Advance in biotechnology.
7. Improvement of environment.

1. Our Environment and Natural Resources

For centuries we have regarded the land, plants and animals for our use. This has caused indiscriminate cutting of forest plants, unmindful use of fossil fuels for burning, and exploitation of all available natural resources for our comfort and satisfy our lust. Our expensive habits have already disturbed the equilibrium of various cyclic phenomena in biosphere.

The human population has become so large that it has threatened our existence on the mother Earth. Human activities have poisoned the biosphere with our wastes and are exhausting the available natural resources. Therefore, the ways in which treat our natural resources and our environment, will determine the quality of life on this planet. Ingenious strategies and efforts are required :

1. To control the uncontrolled growth of human population.
2. To re-establish a close harmony between human population and nature.
3. To sustain development and progress with minimal ecodegradation.

These are the major scientific challanges of future before biologists. These issues have already been highlighted in mass media and environment awareness campaigns. The essential steps to face those challanges can be-

1. Forestation on large scale to regreen the earth.
2. Conservation of wild life in sanctuaries or breeding a rare animal in zoo.
3. Storing valuable germplasm either by conserving rare plants and animals in their natural habitat or storing in a gene bank.
4. Integrated pest management by utilising biologicasl methods, such as sterilising the pests or by using pheromones.
5. Use of biofertilizers to improve land fertility and increase food production to feed every mouth on earth.
6. Minimize the use of chemical pesticides and synthetic fertilisers.
7. Find out alternative sources of energy, so as to become independent of orthodox sources of fuel and energy.
8. To find out methods for making our environment free from various pollutants such as
   (i) treating and biodegrading factory effluents and domestic sewage.
   (ii) reducing lead content in automobile exhaust.
   (iii) minimizing use of insecticides, pesticides and chemical fertilizers.

2. Space Biology

Scientists have established space stations and substations. It is essential to study effect of space on small animals and plants and human beings and find out the possibility of establishing extraterrestrial life and colonization on some planet.

3. Biotechnology

Admirable achievement in the field of molecular biology, recombinant DNA technology, genetic engineering has opened now vistas in the field of

biotechnology. It has helped human race in the commercial production of a large number of useful substance by utilising microbes. The industrial use of microbes in the manufacture of alcohol from molasses, vitamins, enzymes in the production of antibiotics has helped human population remarkably.

By using recombinant technology, scientists have been successful in manufacturing insulin and growth hormone somatotin. We can hope that in future synthesis of other hormones of medical value could also be achieved. This can relieve human population of its various hormonal imbalances.

This technology has also opened a field of correcting the genotype of persons suffering from genetic disorders such as introducing gene for insulin in cells of persons suffering from diabetes.

4. Study of Genotype and Preparation of Chromosome Mode

To locate the position of specific genes on human choromosomes is not an easy task. It is like searching a needle in a haystack. Still scientists have been able to isolate genes by the use of restriction enzymes. However, this is a totallty new field and only in its infancy. It promises a lot for the betterment of human race. **Cell hybridization technique** has helped in locating genes on different chromosomes of human beings and thus finding out the harmful genes or the beneficial genes. Thus this technology has helped in solving problems of health and diseases in human beings and domesticated animals, and providing better varieties of crop plants.

A lot can be achieved and lots of efforts are needed to solve various problems being faced by man in the field of agriculture, environment and industry. Human destiny will depend upon what use man will make of his biological knowledge and what new achievements we plan to fulfill.

CBSE EXAMINATION PAPER

BIOLOGY (Theory) 1990 (XII Class)

(Held for Kendriya Vidyalyas)

Time allowed : 3 hours   *Maximum Marks : 70*

General Instructions :

   (i) All questions are compulsory.

   (ii) Marks for each question are indicated against it.

   (iii) Question nos. 1-11 are very short-answer type and carry one mark only. Answer them in about one word/one sentence.

   (iv) Question nos. 12-23 are short answer questions carrying 2 marks each. It is appropriate to answer them in 20-40 words.

   (v) Question nos. 24-28 are short answer questions carrying 3 marks each. It is appropriate to answer them in about 30-50 words.

   (vi) Question nos. 29-32 are long-answer questions carrying 5 marks each. It is appropriate to answer them in about 40-100 words.

  (vii) Do not unnecessarily make the answers lengtheir than desired.

1. In a wheat field some broad-leaved weeds were seen by a farmer. Which plant hormone would you suggest to get rid of them ?   1

2. Suppose the cells of our skin fail to synthesize keratin, how would it affect us ?   1

3. In an experiment on cells dividing by mitosis, one wants to arrest cells at metaphases. Suggest one chemical which can be used to obtain metaphase chromosomes in large numbers.   1

4. Define lysozymes.   1

5. Name any two characteristics in man which show polygenic inheritance.   1

6. What is integrated pest management ?   1

7. Which organic compounds did Miller and Urey find in their experiments simulating conditions on the primitive earth ?   1

8. Name the two types of sieve elements found in phloem.   1

9. Define analogous organs.   1

10. Point out the wrong item in the following set of structures :

    corpus callosum, premotor area, gyri, motor-end plate, somaesthetic area, association area.   1

11. Botanists are trying to preserve as many plants as possible in viable conditions. Why is it so ?   1

12. Draw a labelled diagram of a ruminant stomach. Indicate by arrows the food movement in it.   2

13. What is a pace-maker ? Why is it called a life-saving instrument ? 2

14. Distinguish between induction and repression. 2

15. A cytologist found that the banding pattern in chromosomes of gorilla and man was similar. What inferences can be drawn from this ? 2

16. Define maternal cytoplasmic inheritance. Give one example from plants. 2

17. What is semi-conservative nature of the replication of DNA ? 2

18. Explain the special points in the nutrition of plants such as *Drosera*. 2

19. If you discovered a fossil of a bird with scales on the body and teeth in the beak, what would you conclude about its position in the animal kingdom ? 2

20. List the main concepts in Darwin's theory of natural selection. 2

21. What are vestigial organs ? How do they support the theory of organic evolution ? 2

22. In an experiment on sweet pea (*Lathyrus odoratus*) a cross was made between two plants one having purple flowers and the other having white flowers. In F_1 all had purple flowers and in F_2 it was a modified Mendelian ratio. 2

    (a) What ratio do you expect in F_2 ?

    (b) What is this phenomenon termed ?

    (c) What are such genes called ? 2

23. Explain how bioconcentration of DDT occurs in the organisms. 2

24. Define seed dormancy. Name any two inhibitory substances which cause seed dormancy. How is this phenomenon important for plants ? 3

25. Draw a labelled diagram of a longitudinal section of an anatropous ovule having two integuments and a micropyle. 3

26. Describe how a nerve impulse is transmitted along a non-myelinated nerve fibre. 3

27. What does AIDS stand for ? How is this disease transmitted ? Suggest two methods for its prevention. 3

28. Define portal system. How is hepatic portal system useful to our body ? 3

29. In what difference forms is the carbon dioxide which is produced in the tissues, transported by the blood up to the lungs ? Explain the steps of release of this CO_2 into the lungs for exhalation. 5

30. Define carbon fixation in plants. What was the contribution of Melvin Calvin in regard to photosynthesis. Describe the three phases of Calvin cycle. 5

31. How is structure of a sarcomere suitable for the contractility of the muscle ? Explain its function according to sliding filament theory. 5

32. What do you understand by biotechnology ? Expalin its use in any four industries. 5